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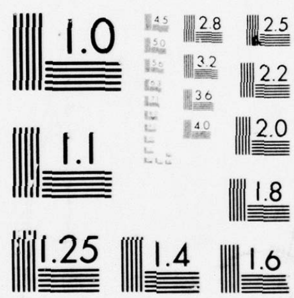

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THE SHOCK AND VIBRATION DIGEST. Volume 9, Number 3. March 1977.

A PUBLICATION OF
THE SHOCK AND VIBRATION
INFORMATION CENTER
NAVAL RESEARCH LABORATORY
WASHINGTON, D. C.

(11) Mar 77

(12) 94p.

OFFICE
OF THE
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THE SHOCK AND VIBRATION DIGEST

Volume 9 No. 3
March 1977

A publication of

THE SHOCK AND VIBRATION
INFORMATION CENTER

Code 8404 Naval Research Laboratory
Washington, D.C., 20375

Henry C. Pusey
Director

Rudolph H. Volin

J. Gordan Showalter

Barbara Szymanski

Carol Healey

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Dr. R. L. Eshleman
Vibration Institute
Suite 206
101 West 55th Street
Clarendon Hills, Illinois 60514

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DIRECTOR NOTES

The shock and vibration community is deeply saddened by the death of Dr. Elias L. Klein on January 9, 1977. He was truly one of the giants of our profession and meant a great deal to me in the early years of my career. Important among his many accomplishments was what is now the Shock and Vibration Information Center. He was also responsible for organizing the first 25 shock and vibration symposia.

How did Dr. Klein impress me when I first met him in 1952? My impression was the same as that expressed by George Bernard Shaw, "Common sense is instinct. Enough of it is genius." I don't pretend that this revelation came to me during our first meeting, because it takes time to fully appreciate such a man. Dr. Klein's notable scientific talents were applied while his feet were firmly on the ground and his head set squarely upon his shoulders. He was more interested in recognizing the work of others than in seeking recognition for himself. The advancement of technology was his goal. He recognized that the future lies with the young and constantly worked to inspire confidence in those he met.

Dr. Klein was my friend. The relationship we had has been described by Emerson, "A Friend is one before whom I may think aloud." During times of uncertainty, I could discuss my alternatives with him and feel assured that his guidance would be constructive. I shall miss him. All those who worked with him will miss him. On behalf of all of us, I extend sincere sympathy to his wife, Bertha. Be assured that he touched the lives of many.

H.C.P.

EDITORS RATTLE SPACE

MOTIVATION FOR REVIEW ARTICLE

Physics Today recently published an editorial by Brian Pippard of the University of Cambridge entitled "Encouraging the Scholar". His opening statement is worth repeating: "I have a modest suggestion to make -- we should take steps to raise the scholarly art of writing review articles to somewhere nearer the status of an original research paper." In Pippard's opinion, a well-written review article should be useful to both young and established scholars and should consolidate knowledge within a specific technical area. He also feels that a good reviewer should be rewarded for this work with some sort of prize.

I agree with Pippard's views and can add a few of my own, namely that a good critical review should contain not only an evaluation and a condensation of knowledge within a small technical area but also information about techniques and data for solving practical problems. It has long been my opinion that a good review article should command a status equal to that of any other scholarly document.

Review articles and tutorials are published regularly in the DIGEST. Even though such articles are not as prestigious in a professional sense as a paper containing original research, some engineers have taken the time to write comprehensive and useful articles. These authors are to be commended for their sacrifices in the absence of any obvious reward, for review articles will attain the status of research articles only when the idea is accepted that both contribute to the literature of a technical area.

Most engineers enjoy reading a well written review, but few are willing to give priority to writing one. Until this priority changes and the status of review articles is raised, few good reviews will be published.

R.L.E.

A REVIEW OF SHOCK RESPONSE SPECTRUM

Yuji Matsuzaki*

The objectives of this paper are to review the principal developments of the shock spectrum technique. Analytical aspects are emphasized. Linear and nonlinear systems are treated separately. Use of the Fourier transform as a descriptor of the shock response is briefly mentioned.

Dynamic responses of a structure subjected to shock loadings are complex. The shock response is determined by vibration characteristics of the structure and the type of loading. In practical design problems, the detailed time history of the response is not always a major concern, but peak responses -- induced maximum displacement, acceleration, strain, and stress -- are significant.

A shock response spectrum is a plot of the peak response of a single-degree-of-freedom oscillator to a specific shock excitation; the spectrum is a function of the natural frequency of the oscillator. Figure 1 shows typical shock spectra of a half-sine pulse for different damping ratios [34]. From these spectra values for the mass, spring stiffness, and damping of the system can be selected so that the response does not exceed a specified limit. If the system parameters are given, an allowable maximum amplitude of the shock load can be determined. The characteristics of the shock force are not necessarily known a priori. Hence it is important to assess the type and severity of the excitation actually applied to a structure. For a seismic-type loading, the shock response spectrum can be obtained relatively easily with a multi-frequency reed gage [36, 40]. Information about ground shock can be expressed in terms of the shock response spectrum.

The concept of the shock response spectrum was originally developed by Biot [5] in 1932 to examine the effects of earthquakes on structures. The shock spectrum approach has been extended and applied to a large number of engineering problems in the areas of seismology [5, 6, 25, 26], nuclear explosions [3, 23], aircraft landings [11, 31], launching and separation of sub-structures of space-vehicles [2, 7], responses of an earth-moving vehicle [30], and package cushioning [34].

*National Aerospace Laboratory, Chofu, Tokyo, Japan

LINEAR SYSTEMS

The equation of motion for a force shock of a single-degree-of-freedom system (Fig. 2) is

$$\ddot{x} + 2\eta\omega\dot{x} + \omega^2 x = \frac{a}{m} f(t) \tag{1a}$$

The equation of motion for a ground shock is

$$\ddot{y} + 2\eta\omega\dot{y} + \omega^2 y = -\ddot{s} = -af(t) \tag{1b}$$

where η, ω, and m are, respectively, damping ratio, natural frequency, and mass. For the force shock, x is the displacement of the mass. For the ground shock y and s are, respectively, the relative and ground displacements. The absolute displacement, x, of the mass is

$$x = y + s \tag{2}$$

The amplitude of the loading function, of (t), is determined by the parameter a because

$$\begin{aligned} &f(t) > 0 \quad \text{for } 0 < t < t_0 \\ &f(t) = 0 \quad \text{for } t \leqslant 0 \text{ and } t \geqslant t_0 \end{aligned} \tag{3}$$

and $\max_{0<t<t_0} f(t) = f(t_m) = 1$

In these equations t_0 is a duration and t_m is a rise time. If f(t) rises monotonically to a peak value and falls back to zero, it is called a simple pulse [13]. The impact load of a typical airplane landing is known as the simple pulse [11].

The solution of equation (1a) for an initial condition $x(0) = \dot{x}(0) = 0$ is described by Duhamel's integral:

$$\frac{kx(t)}{a} = \frac{\omega}{\sqrt{1-\eta^2}} \int_0^t f(\xi)\, e^{-\eta\omega(t-\xi)} \sin\left\{\omega\sqrt{1-\eta^2}\,(t-\xi)\right\} d\xi \equiv X(t) \tag{4}$$

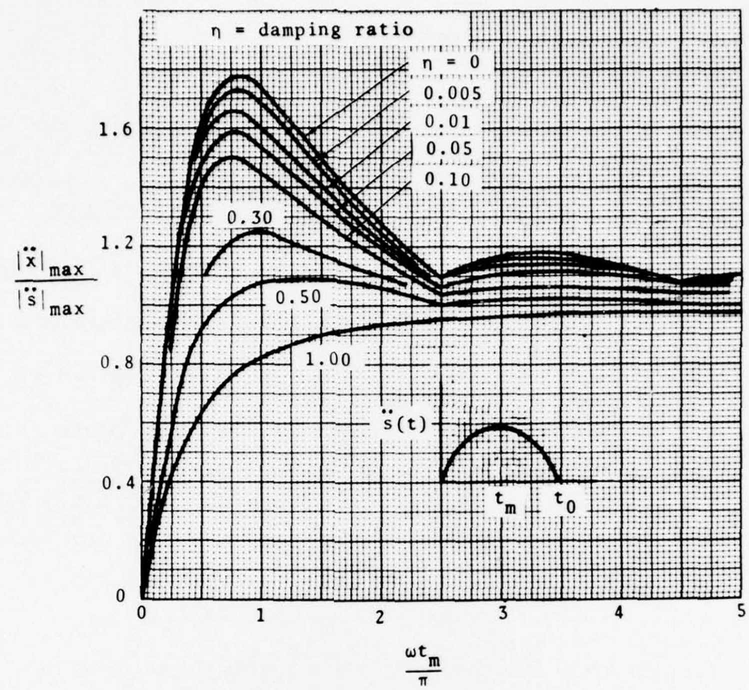

Figure 1. Shock Spectra of a Half-sine Pulse [34]

X(t) is a ratio of the displacement to the maximum static deflection. The time, t_p, at which the response reaches the maximum or minimum peak is given by

$$\left.\frac{dX(t)}{dt}\right|_{t=t_p} = 0 \qquad (5)$$

The nondimensional peak displacement $X(t_p)$ *is a* function of the natural frequency, $S_X(\omega)$; that is, $\max_t \{X(t)\} = X(t_p) = S_X(\omega)$. A plot of $S_X(\omega)$ against a frequency parameter $\omega t_m/\pi$ or $\omega t_0/\pi$ is *called the displacement spectrum, amplification* spectrum, or shock response spectrum. The velocity and acceleration spectra are defined as the peak values of $\dot{X}(t)$ and $\ddot{X}(t)$, respectively; $\max_t \{\dot{X}(t)\} =$ $S_{\dot{X}}(\omega)$. *The peak response, which occurs before or* after $t=t_0$, is called, respectively, the primary or residual shock spectrum. For the ground shock the shock response spectrum can be defined as

$$S(\omega) = \frac{\omega^2 \, |y|_{max}}{|\ddot{s}|_{max}} = \frac{|\ddot{x}|_{max}}{|\ddot{s}|_{max}} = \frac{|\ddot{x}|_{max}}{a} \qquad (6)$$

if the damping is sufficiently small [34].

The shock response spectrum is not as sensitive as the time history of the shock force. This fact was discovered by *Shappiro and Hudson* [40] *and con*firmed by Fung [18].

The spectra for some simple shocks have been evaluated analytically [10, 27]. Analytical calculation of *peak response to an arbitrary shock is usually in*adequate, however, particularly for damped systems. Analog and digital computers are used to obtain shock spectra. Charts of the shock response spectra of a linear, single-degree-of-freedom system are available [1, 4, 17, 37]. A number of analytical

investigations at known frequency ranges have been performed by Fung and Barton [12, 14, 15, 17, 18]. Their theoretical analyses are described below.

Low-frequency Case

For the low-frequency case [12], $\omega \ll 1$, assume that the damping is small -- i.e., $\eta^2 \ll 1$ -- and expand the sine term in equation (4) to obtain

$$X(t) = R(t)\, e^{-\eta\omega t} \sin[\omega t - \phi(t)] \tag{7}$$

where

$$\begin{aligned} R(t) &= \omega (B_c^2 + B_s^2)^{1/2} \\ \phi(t) &= \arctan(B_s/B_c) \\ B_c(t) &= \int_0^t f(\xi)\, e^{\eta\omega\xi} \cos\omega\xi\, d\xi \\ B_s(t) &= \int_0^t f(\xi)\, e^{\eta\omega\xi} \sin\omega\xi\, d\xi \end{aligned} \tag{8}$$

When $\omega \to 0$,

$$\phi \to 0, \text{ and } R \to \omega \int_0^t f(\xi)\, d\xi \tag{9}$$

$R(t)$ increases monotonically with increasing t. Because $\omega \ll 1$, the peak response is considered to occur at $t > t_0$, i.e., after the shock has terminated. For $t > t_0$, R and ϕ are constant. The peak time t_p and the peak displacement can be calculated from equation (7) as

$$\omega t_p - \phi(t_0) = \frac{\pi}{2} \tag{10}$$

$$S_X(\omega) = X(t_p) = R(t_0) \exp[-\eta \{\pi/2 + \phi(t_0)\}] \tag{11}$$

Differentiating equation (11) with respect to ω yields, respectively, the slope and curvature of the shock spectrum at the origin:

$$\left. \frac{dS_X(\omega)}{d\omega} \right|_{\omega=0} = \exp(-\pi\eta/2) \int_0^{t_0} f(\xi)\, d\xi$$

$$\left. \frac{d^2 S_X(\omega)}{d\omega^2} \right|_{\omega=0} = 0 \tag{12}$$

High-frequency Case

For the high-frequency case [12], $\omega \gg 1$, $f(t)$ is not necessarily positive but is assumed to be continuous and differentiable. For simplicity, the zero damping case, $\eta = 0$, is considered. Equation (4) can be rewritten as

$$X(t) = \int_0^t f(t - \xi)\, \omega \sin\omega\xi\, d\xi \tag{13}$$

Integrate parts and use $f(0)=0$ to obtain

$$X(t) = f(t) - \int_0^t \frac{df(t-\xi)}{d(t-\xi)} \cos\omega\xi\, d\xi$$

The integral vanishes as ω tends to infinity according to the Riemann-Lebesque theorem; therefore,

$$\lim_{\omega \to \infty} X(t) = f(t) \tag{14}$$

This means that, if the period of the oscillator is sufficiently short compared with t_0, the response tends to be the same as the loading function. Hence

$$\lim_{\omega \to \infty} S_X(\omega) = 1 \tag{15}$$

In this case t_p is the same as t_m. A more accurate result is possible with an asymptotic expansion method [12].

$$\lim_{\omega \to \infty} S_X(\omega) = 1 - \frac{\dot{f}(0)}{\omega} \sin\omega t_m \tag{16}$$

At the high frequency range the spectrum is a wavy curve with a "period" of $\omega t_m = 2\pi$.

Arbitrary Frequency

For the case of no damping, some analytical expressions for t_p, $S_X(\omega)$, and the slope and curvature of $S_X(\omega)$ have been derived [18].

It follows from equations (15) and (16) that the spectrum of the continuous force tends to unity as $\omega \to \infty$. However, this is not necessarily the case for shocks that are discontinuous with time. For example, the shock spectrum for a square pulse approaches two as ω increases. Fung [14] has presented analytical forms of spectra at high frequencies as well as the shock spectra of the shocks.

The shock spectrum can be used with the normal mode approach to assess the maximum responses of a linear, multi-degree-of-freedom system. The upper

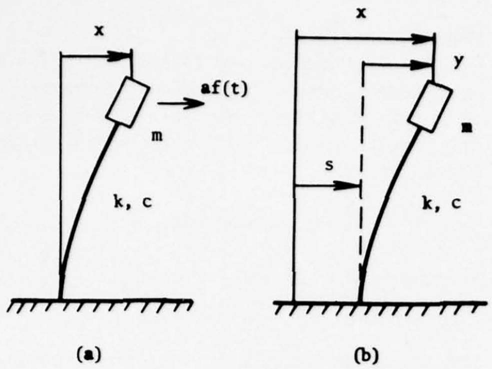

Figure 2. Linear System Models
(a) Force shock, (b) Ground shock
(k: spring stiffness of a massless beam, c: damping)

bound for the maximum response has been estimated by Biot [6]; he superposed the abolute values of the maximum responses for each normal mode:

$$|w(\vec{r}, t)|_{max} \leq \sum_{n=1}^{N} |q_n(t)_{max}| \cdot |\psi_n(\vec{r})| \qquad (17)$$

where w, q_n, and ψ_n are, respectively, the total response, the normal coordinates, and the normal modes that satisfy

$$w(\vec{r}, t) = \sum_{n=1}^{\infty} q_n(t)\, \psi_n(\vec{r}).$$

The symbol $\vec{r}$ denotes a position vector. Equation (17) provides a reasonable upper bound for the response of structures to earthquakes [25]. For the airplane landing problem, however, the results obtained with equation (17) have been found to be too conservative [31]. The maximum response of this complex system has been investigated [18] with a method based on equations (14) and (15). If the frequency parameter is relatively large in the multi-degree-of-freedom system -- i.e., t_0 is large compared with the periods of all the normal modes -- the response of each normal mode should be the same as the forcing function and should peak at $t=t_m$. The peak response of the total system can thus be obtained as a sum of the peak responses of the predominant modes:

$$w(\vec{r})_{max} \cong \sum_{n=1}^{N} q_n(t)_{max}\, \psi_n(\vec{r}) \qquad (18)$$

This estimation is a close approximation but does not assure conservativeness. In order to supplement Biot's simple estimate for the upper bound, Butzel and Merchant [8] proposed a lower bound estimation of the shock spectrum. If the upper and lower bound estimates fall within a narrow region, they provide a powerful tool for evaluating the maximum response of a complex structure.

Because damping influences vibration, the effects of damping on shock spectra have been examined by a number of investigators. Only viscous damping has been studied thus far; shock spectra have been presented as a half-sine pulse [34], a trapezoidal pulse [13], and several shock pulses [37]. Damping is sometimes so small that the undamped spectrum can be used for design purposes. But damping does of course tend to suppress shock response and thus must be accurately estimated. McGrath and Bangs [33] applied a statistical treatment to experimental data to calculate conversion factors for changing spectra from one damping value to another. They assigned a damping value to a system subjected to a known shock at low frequency [32] and calculated a spectrum.

When a mass supported by a spring and a damper is dropped, the acceleration of the mass is a decaying sinusoid. Mindlin [34] used this model for package cushioning analysis and performed a systematic study on the amplification spectra. The shock spectra for a series of decaying sinusoids have been published [4]. The shock spectrum of a decaying sinusoid excitation is similar to a curve of magnification factor of the damped system subjected to undamped sinusoid excitation. Galef [24] used the analytical expression for the amplification factor to propose an approximate formula for the spectrum of the decaying sinusoid.

Actual seismic shocks can be measured with a simple mechanical device called a multi-frequency reed gage; the data can be used to plot a shock spectrum [36, 40]. The reed gage, which consists of a number of single-degree-of-freedom mass-spring systems mounted on a rigid base, can be used in two ways: as a measuring device for ground shocks and as a dynamic

model representing the vibration modes of a structure exposed to a specific shock. The reed gage can be used in strong electro-magnetic fields such as those produced by a nuclear explosion. Reed gages have also been used to specify shot parameters of underground nuclear tests [23].

The shock spectrum is used for analysis and design of both simple and complex systems subjected to shock. The shock spectrum can also be used to describe a shock load. But it cannot always adequately represent all of the essential features of a complicated response. In certain cases, errors may exceed tolerable limits. Schell [39] has pointed out errors inherent in the specification of shock motion with a shock spectrum.

Equipment exposed to a shock may fail as a result of collisions of individual parts. The distance between the colliding parts is important and has been represented as a "proximity spectrum" [38]. The proximity spectrum is the minimum value of the distance between the masses of two uncoupled single-degree-of-freedom systems mounted on a base that is subjected to a shock. The proximity spectrum is plotted against two independent frequency parameters on the horizontal coordinates, forming a three-dimensional surface.

NONLINEAR SYSTEMS

Most engineering structures have nonlinear load-displacement relations near their design limit; these nonlinear effects must be taken into account when the structural response to shock loads is determined. In a nonlinear system superposition cannot be used; each problem must be solved individually. In addition, more parameters are involved in the nonlinear problem than in the linear one. As a result, the response characteristics of the parameters are complicated.

Less work has been published on shock problems of nonlinear systems than on linear ones. In the earliest study in this field [34] package cushioning for several types of nonlinear elasticity of a spring was investigated. In addition, systematic studies have been performed and nondimensional parameters have been defined [16, 19, 20, 44, 45]. The theoretical formulation of Fung, Barton, and Young follows.

Consider a single-degree-of-freedom system with no damping and a nonlinear spring

$$P(z) = k\,[z + Q(z)] \qquad (19)$$

where z and $Q(z)$ represent, respectively, a deflection and a nonlinear effect of the spring. For purposes of illustration, the system is subjected to a ground shock and has a cubic softening spring described by

$$P(y) = ky - k_3 y^3 \qquad (20)$$

The equation of motion is

$$\ddot{y} + \omega^2 (y - \lambda y^3) = -\ddot{s}(t) = -af(t) \qquad (21)$$

where

$$\lambda = \frac{k_3}{k} \qquad (22)$$

It is helpful to use the corresponding linear system as a reference. The linear system is obtained from the nonlinear one by eliminating the nonlinear effect. The equation of motion for the linear system is

$$\ddot{y}_0 + \omega^2 y_0 = -\ddot{s}(t) = -a_0 f(t) \qquad (13)$$

The suffix "0" is attached to the displacement and amplitude of the forcing function of the corresponding linear system. The load-displacement curves of the nonlinear and linear systems are illustrated in Figure 3.

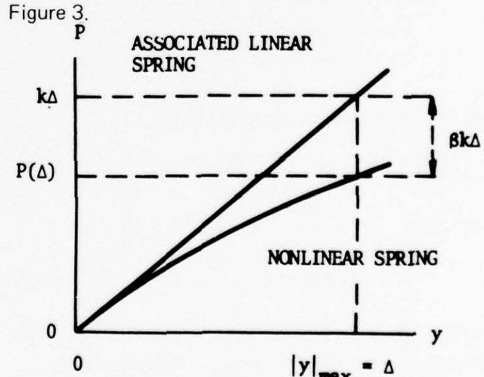

Figure 3. Load-displacement Curves of a Nonlinear System and Its Corresponding Linear System

In order to specify the nonlinearity of the problem in a compact form, Fung and Barton [19] introduced a β-parameter, which they defined as follows. Let the maximum allowable deflection be denoted by Δ ; the maximum spring forces are $P(\Delta)$ for the nonlinear spring and $k\Delta$ for the linear spring. The nonlinear parameter β is defined in terms of these spring forces as

$$\beta = \frac{k\Delta - P(\Delta)}{k\Delta} = 1 - \frac{P(\Delta)}{k\Delta} \tag{23}$$

for the cubic softening spring

$$\beta = \lambda\Delta^2 \tag{24}$$

In addition, Young, Barton, and Fung [45] defined two shock spectra analogous to the spectrum given by equation (6). One is a nondimensional absolute acceleration spectrum

$$\bar{S}(\omega, a, \beta) = |\ddot{x}|_{max}/a \tag{25}$$

The other is a nondimensional relative displacement spectrum

$$S^*(\omega, a, \beta) = \omega^2 \, |y|_{max}/a \tag{26}$$

Two spectra for the nonlinear system are required because $|\ddot{x}|_{max} \neq \omega^2 |y|_{max}$.

The following nondimensional parameters

$$z = \omega^2 y/a$$

$$\tau = \omega t \tag{27}$$

$$c = \frac{a^2}{\omega^4}\lambda = \frac{\beta}{(|z|_{max})^2}$$

can be used to rewrite equation (21) as

$$\frac{d^2 z}{d\tau^2} + z - cz^3 = -f\left(\frac{\tau}{\omega}\right) \tag{28}$$

Note that

$$|z|_{max} = S^* \tag{29}$$

For specific values of ω and c, solve equation (28) numerically to obtain $|z|_{max}$. Substitute $|z|_{max}$ in the third nondimensional parameter of equation (27) to calculate β:

$$\beta = (|z|_{max})^2 \, c = (S^*)^2 \, c \tag{30}$$

This procedure can be repeated for a range of values of ω and c. These values can be used to plot curves of S^* against the frequency parameter for several βs. The resulting spectra can be used so that the peak value of the response of the nonlinear spring has a specified limit. Such applications of spectra to analysis and design problems have been explained in detail [45].

If the amplitude of the shock is the same in the nonlinear and corresponding linear systems -- i.e., if $a = a_0$ -- the maximum static deflection of the linear system, Δ_{st}, is

$$\Delta_{st} = \frac{a}{\omega^2} \tag{31}$$

Hence, the coefficient of the nonlinear term in equation (28) can be rewritten as

$$c = \lambda\Delta_{st}^2 \tag{32}$$

It has been shown that this physical interpretation for c is a meaningful alternate to the nonlinear parameter β [44].

Other useful descriptors of the response characteristics of nonlinear systems include loading ratio L, displacement ratio H, and acceleration ratio J [19]. The loading ratio is defined as the ratio of ground acceleration amplitudes that produce the specified maximum relative displacement in nonlinear and corresponding linear systems.

$$L(\omega, a, \beta) = \frac{a}{a_0} \quad \text{for } |y|_{max} = |y_0|_{max} = \Delta$$

The displacement ratio is the ratio of the peak relative displacement of the nonlinear and linear systems subjected to a ground acceleration of the same amplitude.

$$H(\omega, a, \beta) = \frac{|y|_{max}}{|y_0|_{max}} \qquad \text{for } a = a_0$$

The acceleration response ratio is the ratio of the peak absolute acceleration of the masses in both systems when the peak relative displacement is the same, that is,

$$J(\omega, a, \beta) = \frac{|\ddot{x}|_{max}}{|\ddot{x}_0|_{max}} \quad \text{for } |y|_{max} = |y_0|_{max}$$

Among the useful relationships between parameters and spectra of nonlinear systems are the following

$$H = \frac{1}{L}, \quad J = 1 - \beta,$$
$$S^* = S(\omega)/L = S(\omega)\, H,$$
$$\bar{S} = S(\omega)\, J/L = S^* J$$

$S(\omega)$ is the shock spectrum of the corresponding linear system. Loading and displacement ratios have been applied in a force shock problem [19].

A bi-linear single-degree-of-freedom system has been analyzed by a number of investigators [41, 43, 45]. The analysis can be divided into a linear region and a plastic, or second linear region. The governing equation in each region is linear. The velocity obtained at the limit of the first region is an initial condition of the velocity in the second region. The shock spectrum defined in the linear system can be directly applied to the response in the second region. Such a nonlinear system has no inherent analytical and numerical problems. But this does not mean that analyses of bi-linear systems are of little importance from a practical point of view. A straighforward analytical treatment of the peak response to a sawtooth pulse has been presented [43]. The phase-plane method is a powerful tool for solving nonlinear equations and has been applied to the peak response analysis of a simple, bi-linear single-degree-of-freedom oscillator [41].

In a linear system having many degrees of freedom, shock spectra of various single-degree-of-freedom oscillators are used with the aid of superposition of the normal modes. Because the principle of superposition is not valid in the nonlinear system, however, response characteristics of a single-degree-of-freedom system are of no use. The shock spectra and various ratios of the nonlinear single-degree-of-freedom system have been extended to the peak response analysis of a nonlinear, multi-degree-of-freedom system. A numerical example of a two-degree-of-freedom system has been published [16, 20]. Kemper and Ayre [30] modeled earth-moving vehicles as a four-degree-of-freedom system with nonlinear springs and dampers; these were expressed as families of exponential functions, and optimal spring and damper combinations were calculated.

FOURIER TRANSFORM OF A SHOCK LOADING FUNCTION

The shock spectrum, although it is a simplified representation of complicated dynamic responses, is useful for many applications. Because it does not represent a time history of the shock response, however, the shock spectrum contains inherent errors that cannot always be neglected. The Fourier transform of an arbitrary time function is mathematically equivalent to the time function, and the Fourier spectrum can be obtained rapidly and inexpensively with fast Fourier transform techniques [21]. Hence, the Fourier transform is useful for describing shock motion and response. It is well known that, for the case of zero damping, the absolute magnitude of the Fourier spectrum of an applied shock is related to the residual shock spectrum [37]. The running Fourier transform can also be used to describe the shock response. Fourier transforms have been applied to shock analysis [28].

The Fourier and running Fourier transforms, with respect to the frequency of the oscillator, ω, and the shock function $f(t)$ given by equation (3) are, respectively,

$$F(\omega) = \int_{-\infty}^{\infty} f(\xi)\, e^{-i\omega\xi} d\xi \tag{33}$$

and

$$F(t, \omega) = \int_{-\infty}^{t} f(\xi)\, e^{-i\omega\xi}\, d\xi \tag{34}$$

For $t > t_0$,

$$F(t, \omega) = F(\omega)$$

Damping is assumed to be zero. Apply the running Fourier transform to equation (1a), integrate by parts, and divide by a/k to obtain

$$\dot{X} + i\omega X = \omega^2 e^{i\omega t} F(t, \omega) \tag{36a}$$

where

$$X = \frac{kx}{a} \tag{4}$$

Substitute $-\omega$ into ω of equation (36a):

$$\dot{X} - i\omega X = \omega^2 e^{-i\omega t} F(t, -\omega) \tag{36b}$$

From equation (36):

$$\dot{X}^2 + \omega^2 X^2 = \omega^4 \, |F(t,\omega)|^2 \tag{37}$$

Note that half of the left side of equation (37) represents total energy that is imparted to the system.

The running Fourier transform is assumed to be in the form of

$$F(t,\omega) = A(t,\omega)\, e^{-i\phi(t,\omega)} \tag{38}$$

where

$$A(t,\omega) = |F(t,\omega)| \qquad \text{for } 0 < t < t_0$$

$$= |F(\omega)| \qquad \text{for } t > t_0$$

$$\phi(t,\omega) = -\phi\,(t,-\omega)$$

$$= -\arctan\,(\mathrm{Im}[F(t,\omega)]/\mathrm{Re}[F(t,\omega)]) \quad \text{for } 0 < t < t_0$$

$$= -\arctan\,(\mathrm{Im}[F(\omega)]/\mathrm{Re}[F(\omega)]) \quad \text{for } t > t_0$$

$A(t, \omega)$ is an absolute magnitude of the running Fourier transform. Let the maximum value of $A(t,\omega)$ be $S_A(\omega)$; i.e.,

$$S_A(\omega) = \max_t \left\{ A(t,\omega) \right\} \tag{39}$$

In other words, $S_A(\omega)$ is an amplitude spectrum of the running Fourier transform. Solve equation (36) to obtain

$$X(t) = \omega A(t,\omega) \sin\,[\omega t - \phi\,(t,\omega)]$$

$$\dot{X}(t) = \omega^2 A(t,\omega) \cos\,[\omega t - \phi\,(t,\omega)] \tag{40}$$

From equations (39) and (40):

$$S_X(\omega) = \max_t \left\{ X(t) \right\} < \max_t \left\{ \omega A(t,\omega) \right\} = \omega S_A(\omega) \tag{41}$$

Similarly,

$$S_{\dot{X}}(\omega) < \omega^2 S_A(\omega) \tag{42}$$

Equations (41) and (42) indicate that $\omega S_A(\omega)$ and $\omega^2 S_A(\omega)$ are the upper bounds for the displacement and velocity spectra, respectively. Since $A(t,\omega) = |F(\omega)|$ for $t > t_0$, it follows from equation (40) that the residual spectra of displacement and velocity are $\omega|F(\omega)|$ and $\omega^2|F(\omega)|$, respectively [37] and that

$$S_X(\omega) > \omega\,|F(\omega)|$$

$$S_{\dot{X}}(\omega) > \omega^2\,|F(\omega)| \tag{43}$$

This method has been applied to a numerical example of an earthquake acceleration. The upper bounds were close to the displacement and velocity spectra over a wide frequency range [28]. The Fourier spectrum of a lightly damped decaying sinusoid contains a severely responding peak. Gaberson and Pal [22] proposed an estimate for the damping ratio of the sinusoid from such a peak of the plot of the Fourier spectrum.

CONCLUDING REMARKS

The shock spectrum is useful for analyzing and designing various structures exposed to a shock load. In addition to the papers listed in the reference, numerous articles treating practical applications of the shock spectrum have been published. Analytical treatment of the shock spectrum is not always feasible, especially if damping is included. However, theoretical analyses, even though they are limited, help us to understand the general features of the response characteristics. For practical purposes "shock spectrum analyzers" [29] are useful. The use of the running Fourier transform as a descriptor of the shock response deserves further study.

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LITERATURE REVIEW

survey and analysis of the Shock and Vibration literature

The monthly Literature Review, a subjective critique and summary of the literature, consists of two to four review articles each month, 3,000 to 4,000 words in length. The purpose of this section is to present a "digest" of literature over a period of three years. Planned by the Technical Editor, this section provides the DIGEST reader with up-to-date insights into current technology in more than 150 topic areas. Review articles include technical information from articles, reports, and unpublished proceedings. Each article also contains a minor tutorial of the technical area under discussion, a survey and evaluation of the new literature, and recommendations. Review articles are written by experts in the shock and vibration field.

This issue of the DIGEST contains review articles on turbine blading excitation and vibration and on the dynamics of cam mechanisms. Dr. J.S. Rao of the Indian Institute of Technology reviews the literature on blade excitation forces, vibration of blades with large aspect ratio, disk-blade interaction, vibration of blades with small aspect ratio, and experimental methods.

Dr. Chen of Ohio University reviews the dynamic aspects of the cam mechanism including kinematics, system modeling and analysis, and system response.

TURBINE BLADING EXCITATION AND VIBRATION

J. S. Rao*

Abstract - This article reviews the literature on blade excitation forces, vibration of blades with large aspect ratio, disk-blade interaction, vibration of blades with small aspect ratio, and experimental methods.

Methods for determining natural frequencies of single and packeted turbine blades have been reviewed [51]. This article is a review of methods used to study theoretical and experimental aspects of the blades used in turbomachinery.

BLADE EXCITATION FORCES

Most turbomachinery blade failures result from fatigue caused by operation of the machine at or near resonant conditions of a blade. It is possible to design blades for smaller machines so as to avoid resonant or near-resonant conditions. As the size of the machine increases, however, it is impossible to avoid near-resonant conditions for some blades. In theory, the dynamic stresses of blades subjected to fluctuating forces should be calculated. In practice, the determination of these forces is difficult.

The determination of the non-steady forces acting on turbomachinery blades involves both solid and fluid mechanics. Meaningful formulas for expressing the lift and moment of an oscillating aerofoil and a plane aerofoil entering a sharp-edged gust were derived as long ago as 1938 [31]. Flow was assumed to be potential and two dimensional; thin aerofoil theory was used. The trail of vortices was assumed to be a wake having the shape of a thin vortex sheet. Lift and moment were calculated from induction effects on the blade profile. Both translatory and torsional oscillations about an arbitrary axis have been studied for thin aerofoils and small amplitudes of oscillation [71]; expressions for the lifts and moments have also been derived. The early work [31] has been extended to account for a series of sinusoidally distributed transverse gusts; the non-steady lift and moment expressions on a single aerofoil were determined. Kemp [32] has studied the wake effects of stator blades on rotor blades of a simple turbomachine having a row of each blade type.

The theory of single thin aerofoils in nonuniform motion has been applied to calculations of the non-steady lift and moments of stator and rotor blades [34]; incompressible and inviscid flow and the transverse gust effect were considered. It was assumed that non-steady effects at any blade were influenced only by steady circulation and not by non-steady effects of other blades. Effects of the passage of rotor blades through the vortex wakes of stator blades were also investigated. A computer program has been developed to determine the non-steady lift on both stator and rotor blades [62].

The effect of viscous wakes has also been studied [35]. The flow from the stator blades was represented with an inviscid shear flow; experimental results were used [72]. Davis [12] determined the stimuli coefficients of blade excitation forces. A direct integral equation approach has been used to determine the lift forces [41]; the effects of trailing vortices of neighboring blades of a passive cascade were also studied. A general computer program has been developed for determining blade forces [53]. Mani [43] considered compressibility effects. Strain gage tests have been conducted for the last three stages of a low-pressure steam turbine to determine the sources of low harmonic blade vibration excitation [49].

The interaction between blade rows in turbomachines has been described [48]. The analysis for a single blade has been used to calculate the non-steady lift on cambered blades moving through periodic wakes in an axial flow turbomachine [46]; design charts were expressed in terms of blade row geometry. In an experimental study [1] the fluctuating forces on stationary blades were measured for various axial distances between blade rows; the results were compared with the theory [34]. Lift and moment expressions for arbitrary power law upwash have been derived from results of generalized sinusoidal gust, in oscillating subsonic non-steady thin aerofoil theory [33].

*Head, Industrial Tribology, Machine Dynamics and Maintenance Engineering Ctr., Indian Institute of Technology, Delhi, India

Horlock [28, 29] determined lift fluctuations on an aerofoil due to a gust parallel to the undisturbed flow; the results were combined with Sears analysis [71]. A new function called Horlock's function, similar to Sears' function, was developed to relate the non-steady lift of a flat plate aerofoil at a prescribed angle of attack to a velocity fluctuation parallel to the chord. This analysis was used to study fluctuating lift on a rotating fan or compressor blade moving through a flow disturbance and to determine the non-steady lift of an aerofoil subjected to a non-convecting stream-wise gust [28]. Experimental results with transverse gust [27] showed good agreement with Kemp's theory [32]. Previous work on flat plates was extended to cambered thin aerofoils [46]; transverse and chordwise disturbances, as well as the angle of incidence, were considered. The analysis of single aerofoils has been extended to a single row of cascaded blades [24, 86]. Both upwash and downwash velocities due to vorticities concentrated at several points along the chord were studied.

The relative importance of sinusoidal gust response functions to aeroelastic analysis has been discussed [5]. It was concluded that, for general compressor design practice, the primary non-steady lift is attributable to transverse gusts alone. In a study of the effects of both stream-wise and transverse gusts, however, the stream-wise gust was shown to be important in determining non-steady lift forces of turbomachinery blades [66]. The lift and moment of a parabolic cambered aerofoil subjected to non-convecting stream-wise gusts were also determined [65]. This analysis can account for the effect of camber on non-steady forces of turbomachinery blades. A water table has been used to determine such non-steady forces [70].

VIBRATION OF BLADES WITH LARGE ASPECT RATIO

Equations of motion for rotating pre-twisted blades in bending-bending-torsion have been derived to determine such effects as warping, shear, and rotary inertia. The equations of motion according to beam theory are six partial differential equations; they are coupled between two bending deflections, two shear deflections, the torsional deflection, and the longitudinal deflection. Axial vibration is ignored because the blade is rigid and steam excitation is unlikely. Recent solutions for special cases are reviewed below.

The extended Holzer method has been used to determine natural frequencies and mode shapes of lateral vibration; the effects of pre-twist and rotation were included [60]. The Myklestad method has been applied to studies of the effects of flexibility of the root on tapered blades [45]. The natural frequencies of tapered rotating blades have been determined by the Rayleigh-Ritz method [63].

The variational principle was used in deriving equations of motion for stationary packeted blades in tangential vibration [52]. A computer program has been described that is capable of determining steady-state stress and displacement, natural frequencies and mode shapes, and forced damped vibration when the aerodynamic excitation of packeted blades is known [50]. The finite element method has been used to determine the natural frequencies of packeted blades in coupled bending-bending-torsion modes [6]; 186 degrees of freedom were used.

The effects of asymmetry, disk radius, and rotation on coupled bending-torsion vibrations of turbomachinery blades have been presented in non-dimensional form [56]. A solution of this problem by the polynomial frequency method [57] was compared with a solution by the Galerkin method [30]. A hollow blade damped with a vibrating beam has been studied [30]. The Galerkin finite element method has been used to determine the effect of taper on natural frequencies of rotating cantilever blades [37]. Natural frequencies of tapered pre-twisted rotating cantilever blades determined by the Rayleigh-Ritz method have been compared with experimental values [64]. An improved method of searching for the root in the Myklestad method saves considerable computer time in determining natural frequencies [13]. A finite difference method has been used to study the double taper effect on bending frequencies of cantilever beams [80]. Nagraj [44] used the matrix displacement technique to determine coupled bending-bending-torsion vibration characteristics of a rotating blade.

The finite element method was used to determine the effect of root flexibility on the vibration characteristics of tapered blades [74]. The same method was used to study coupled bending-bending-torsional

vibration; natural frequencies of a typical turbomachinery blade were also calculated [73]. Tomar and Koorich [82] used the Rayleigh quotient method for the nonlinear vibration problem of a tapered rotating blade. Anderson [3] has treated extensional and flexural vibration of rotating bars. Results based on the extended Galerkin method have been compared with experimental values for flexural vibration of rotating blades [85]. Design information in terms of non-dimensional parameters has been used to determine the natural frequencies of turbomachinery blades [54]; such effects as taper, pre-twist, asymmetry of cross section, disk radius, rotation, shear deflection, rotary inertia, and stagger angle were considered. Coupled bending-torsion natural frequencies of rotating blades determined with the Galerkin method showed good agreement with experimental values [58]. The effects of rotary inertia and shear deflection were presented in useful design charts [59]. Three coupled equations of a pre-twisted blade having an asymmetric cross section and mounted on a rotating disk at a stagger angle were derived by the Galerkin method [55].

DISK-BLADE INTERACTION

Few studies have been done with regard to the effect of disk elasticity on blade vibration. A set of blades mounted on a rotor exhibit more complex vibration characteristics than do single or packeted cantilever blades. A receptance coupling procedure has been used to determine natural frequencies of the bladed system [4]. The blades were assumed to be identical, and the form of vibration modes was also assumed; results were compared with experimental values. The effect of small differences between blades -- i.e., differences in tuning and damping -- on the vibration properties of bladed disk assemblies has been studied [18, 19]. It was shown that blade imperfections cause vibration levels 20% in excess of those of tuned blades. Whitehead [87], Wagner [84], and Lye and Henry [17] also considered detuned blades. The finite element method has been used [36]; rotation and temperature loading were considered.

The receptance method has been used to study a bladed disk assembly containing 24 detuned blades [20]. The analysis was extended to a staggered and shrouded blade disk assembly [21]. The system can have a number of double roots and two vibration modes for certain natural frequencies. Experiments on disk assemblies with and without shroud were in good agreement with the theory. Cottney and Ewins [11] have also considered shrouded blade disk assemblies.

VIBRATION OF BLADES WITH SMALL ASPECT RATIO

Shell analysis is used to analyze small aspect ratio blades. The finite element method has been used to determine static deflections of a pre-twisted cantilever plate [68]. Pre-twists were up to 90 degrees; flat plate triangular elements were up to 10 x 10 mesh. This analysis was later extended to determine the natural freuqencies and mode shapes of pre-twisted cantilever plates [69]. The stresses, frequencies, and mode shapes of an existing stationary thin blade have been studied by the finite element method [7]. A similar analysis has been done for thick blades [2] and extended to rotating blades [8]. Dokainish and Rawtani obtained modified Southwell coefficients for rotating thin plates [15] and considered the effect of pseudo-static deformation on the natural frequencies of rotating small aspect ratio blades [16]. Hofmeister and Evensen [24] prefer isoparametric elements in calculating natural frequencies of non-rotating blades. Slingerland [75] suggested a new equation for analysis of experimental results obtained by the Moire technique with turbine blades. Thin rotating cantilever plates have been analyzed with the finite element method [14]. Frequencies and mode shapes of thick rotating blades have been calculated [81]. The effect of camber on natural frequencies of small aspect ratio turbine blades has been studied [67]. Frequencies and mode shapes of thin rotating blades have been determined and a design procedure suggested [25]. Lalanne and Trompette [39] used isoparametric elements in a dynamic analysis of actual turbine blade; they included the effects of root influence and temperature. A method for obtaining a mathematical model of rotating blades with Lagrange's equations and the finite element method has been used to calculate the natural frequencies of a gas turbine blade and an air compressor blade [40].

Macbain [42] used four node quadrilateral plate-bending element CQUAD2 of NASTRAN to evaluate the natural frequencies of a 2.33 aspect ratio blade for different pre-twists and a mesh size of 11 x 24. The results agreed fairly well with experimental

results. The variation of first and third mode bending results were contradictory to other results with respect to pre-twist in the flexible direction [69]. The theory of elasticity was used to determine the natural frequencies of thin pre-twisted plates [22]. Their results for flexural vibration agreed well with those of Macbain [42]. Gupta and Rao [23] determined the torsional vibration of small aspect ratio pre-twisted plates.

EXPERIMENTAL METHODS

Low-speed tests have been run on a rig designed to run at 20,000 rpm that was modified by relocating the slip ring in its own bearings outside the chamber; the slip ring was connected to the rotor with a flexible coupling and a drive shaft assembly passing through the vacuum door [10]. The Moire technique has been used to determine blade vibration characteristics [75].

Kulczyk and Davis [38] have developed a laser doppler instrument; a one mw laser is used to measure the vibration of rotating turbine blades. The main advantage of such a method is that there is no contact between the conventional pick-up or strain gage mounted on the blades and lead wire connections. Poor signal/noise ratios cause large measurement errors, however, and the method is limited to applications in which flight paths for light beams are accessible. The statistical nature of proximity-probe signals has been analyzed and an estimate for the power spectral density function of blade vibrations has been given [47].

Tests have been conducted on static blades to evaluate root flexibility factors [45, 83]. Test results of a series of measurements on industrial gas turbines and axial compressors have been published [75]. A rotating test rig driven by compressed air jets has been described; test results of tapered pre-twisted blades for speeds up to 10,000 rpm were given [79]. Laser holography has been used to determine the natural frequencies of small aspect ratio blades [42]. Rao and Banerji [58] described a rig for testing asymmetric rotating blades up to 5,000 rpm.

The incidence of blade failure and deficiencies in Indian designs have been surveyed [9]. Sohre [76] evaluated tests of mechanical-drive turbines for thermodynamic performance and mechanical reliability, including coupled disk-blade modes. He has also discussed the causes of steam turbine blade failures and possible remedial actions [77].

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A REVIEW OF THE LITERATURE ON THE DYNAMICS OF CAM MECHANISMS

Fan Y. Chen*

Abstract - This article contains a literature survey of the dynamic aspects of the cam mechanism, including the kinematics of cam profiles, system modeling and analysis, system response, and design methods.

Improper function of valve gears, which causes noisy operation of engines, excessive spring surge, valve seat pounding, and burning, has been studied since the 1930s. Harmonic analyses of cams and the vibration analyses of valve springs in internal combustion engines were carried out in the mid 1930s in attempts to reduce resonant vibration [67, 68, 96]. The significance of the flexibility of the cam follower linkage was first pointed out in 1939 [115]. In 1963 the cam-and-follower system was simulated as a simple spring-mass model on a differential analyzer [65]. The first experimental verification of poppet valve dynamics was conducted in 1950 [103]; the vibration characteristics of the follower of three basic motions -- parabolic, simple harmonic, and cycloidal -- were recorded.

Turkish [140 - 141] measured the frequency of valve gear vibration by monitoring cam velocity with a magnetic velocity transducer mounted on the engine unit. He used an electronic acceleration analyzer to measure the actual acceleration of a cam. Valve jump behavior was measured in 1953 with high-speed motion picture photography [136]. Barkan [10] used a resistance-type strain gage mounted on the upper rocker arm of the valve gear unit to obtain dynamic strain records.

KINEMATICS OF CAM PROFILES

Standard Functional Profiles

At one time hand calculation and graphical layout were the only techniques available for designing cam profiles. Early graphical techniques included such simple geometric curves as circular arc segments, parabolic curves, and simple harmonic curves. The techniques used now reflect lower forces on the cam; such curves as cycloids and trapezoids [33, 97], modified paraboloids, modified cycloids [2, 70, 149], modified trapezoids [1, 112, 113], modified sinusoids [122, 131], and polynomials are used. Figure 1** lists basic cam motions of the dwell-rise-dwell event. The curves representing velocity, acceleration, and jerk are based on a unit total lift h that corresponds to a unit cam angular displacement. Figure 1 is a ready reference for curve contour and shows the comparative values of peak velocity, acceleration, and jerk.

Attenuated Harmonic Profiles

Because the motion of a cam is inherently periodic, harmonic series analysis of cams is possible, and attenuated harmonic series analysis has been suggested as a means for establishing cam profile specifications [8, 47, 53, 56, 119]. The accuracy of the analysis depends primarily upon the number of terms in the Fourier series representing the cam profile. The truncation required with such a series and its uncertain mathematical convergence make difficult the determination of the number of terms necessary to guarantee accuracy at the end points of the motion range. Furthermore, profile harmonics and system resonance can seldom be correlated because the correlation depends on predetermination of cam velocity, which usually cannot be predicted. The requirements of the profile are therefore satisfied with a curve having a few low harmonics. General discussions on the use of harmonic series in cam profile design have been published [56, 145].

Algebraic Polynomial Profiles

The "polydyne" method of Dudley and Stoddart [45, 136] requires simultaneous solution of a set of equations to satisfy the imposed kinematic boundary conditions resulted in the generation of algebraic polynomials for cams. The acceleration curves obtained with the polydyne method are often erratically shaped toward one end of the motion stroke. Consequently, the displacement curve is flattened at the start and end of the motion; this means that much of the allotted drive time is wasted. Comments on the polydyne method have been published [50, 73, 97,

*Department of Mechanical Engineering, Ohio University, Athens, Ohio 45701

**Some of the cam curves are available [78].

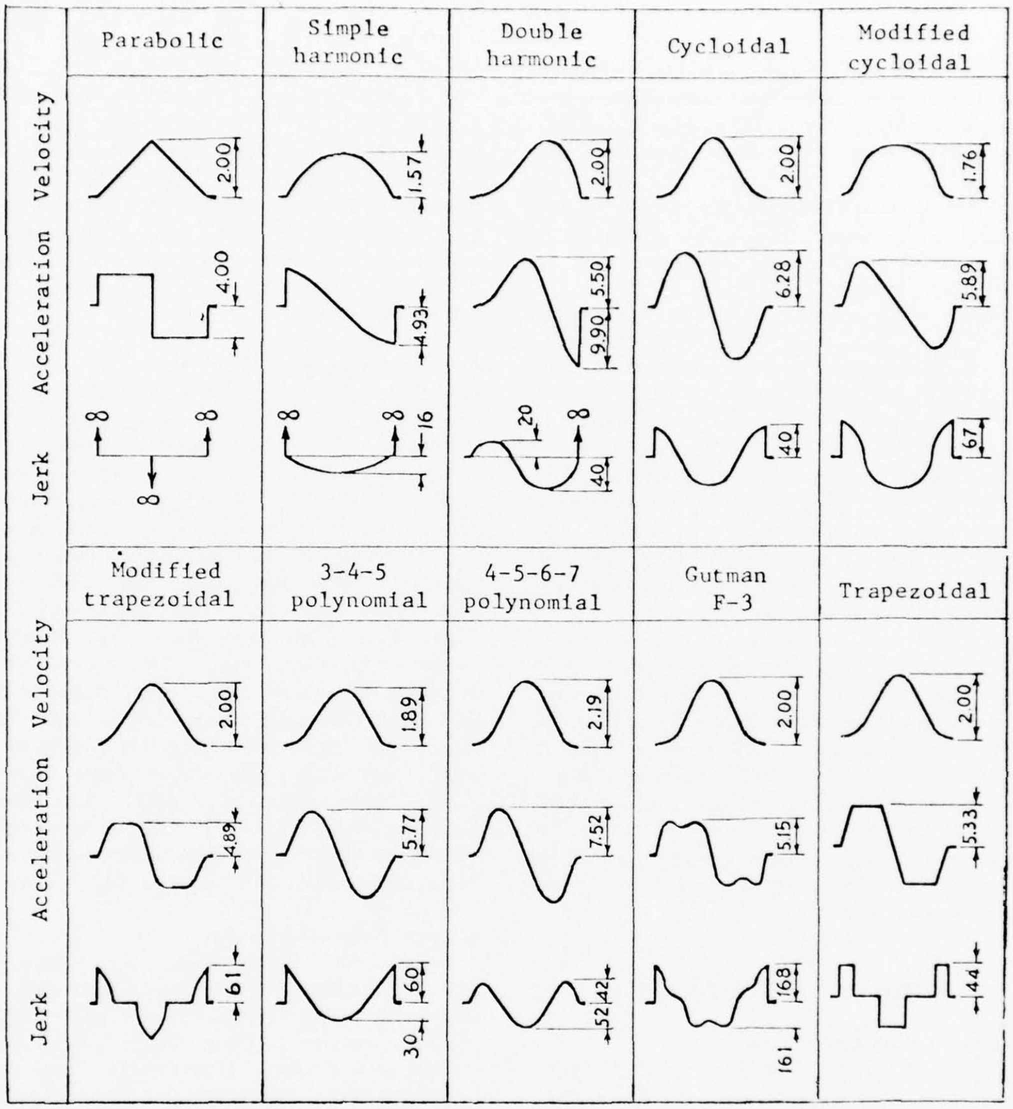

Figure 1. Basic Cam Motions

117]. A simple method that allows local control without the need to regenerate a family of polynomial curves has been presented [97].

Profile Synthesis by Numerical Methods

The procedure for synthesizing cam profiles consists primarily of developing, by a prescribed procedure, an acceleration curve; a corresponding displacement curve is generated from the acceleration curve by numerical integration and curve fitting. The equally-spaced three-point central-difference formula for fitting the cam profile was first used in the mid-1950s [75, 76]. The method requires compilation of a difference table and fitting data to points. A change of acceleration data may produce an erratic displacement curve; in general, the shape of the displacement curve should change as little as possible. Several adjustments may be necessary to obtain the desired cam profile.

A simple inductive formula for synthesizing cam profiles of dwell-rise-dwell type has been derived [26]; it is based on a finite-difference scheme. Two methods for achieving numerical accuracy in the synthesis of cam profiles for arbitrarily prescribed accelerations have also been developed [27, 28]. In the first, a finite integration method [28], mechanical quadrature formulas are used to construct an "integrating matrix." In the second a data refinement process is applied to the initially specified acceleration values [27]. These methods have been used to derive three versions of recurrence law [41 - 43]; displacement is related directly to jerk in order to synthesize cam profiles for a prescribed pattern of jerk values. Recently, Matthew and Tesar [97] suggested a singularity function formulation to synthesize cam profiles with trapezoidal acceleration or jerk specifications.

Pressure Angle and Radius of Curvature

The development of a sound cam profile requires a clear understanding of basic kinematic and force factors and their effects. Basic factors include continuity in acceleration curves, low maximum values in velocity, and maintenance of adequate radius of curvature.

Cam pressure angles have been described [80, 84, 128], as has determination of the radius of curvature, [13, 25, 63, 82, 83, 121]. Design charts are available [82, 83] for maximum values of pressure angles and curvatures for harmonic, cycloidal, and eighth-degree polynomial motion for cams with either a radial roller follower or an oscillating roller follower. The ordinates of these charts are nondimensional and are thus applicable to any case associated with a relevant kinematic mode.

Evaluation of pressure angle and determination of normal and principal curvatures in three-dimensional cams pose a difficult problem. A theory for performing closed-form analysis using relative velocity vector with geometric transformation matrices has been developed [38-40].

DYNAMICS OF CAM-AND-FOLLOWER SYSTEMS

In addition to the cam profile, the parameters of the follower linkage, including mass distributions, characteristic frequencies, damping factors, and nonlinearities, affect system response. As machine speed increases, the dynamic behavior of the cam-and-follower system become more difficult to predict and control. The difficulty is compounded when the nonlinearities of the system are taken into consideration.

System Modeling

The cam-and-follower system can consist of one or more rods, levers, and springs. All of these components have mass and elasticities distributed throughout the system in accordance with their physical dimensions.

The dynamic model of a cam-and-follower system is usually a simple spring-mass system; this system is achieved by lumping the effective mass of the follower at one point. The linkage elasticity is approximated with a single spring that supports the effective mass. The values of the effective mass and spring stiffness are based on the principle of kinetically equivalent systems described in standard textbooks.

Experimental evidence indicates that the single degree-of-freedom model was satisfactory for studying the automotive valve gear. Dynamic studies of cam-actuated systems in automatic machines can be expressed realistically only with two or more independent displacement coordinates. The vibration analysis of flexible cam-and-follower systems has been extended to models having two degrees of

freedom [46, 77, 98, 99]. Dimensionless design charts show the effects of parameters, rules of thumb simplify the design procedure [98, 99]. A multi-degree-of-freedom model has been used [74] in a computer study of the valve train dynamics of a General-Motors four-valve diesel engine model; valve velocity data were recorded with a light velocity pickup. Oscilloscope records of velocity were calibrated for the valve; corresponding values of displacement and acceleration were obtained by integration and differentiation of the velocity signal.

It has been common practice to assume linearity for a nonlinear system because a nonlinear system is inherently more difficult to analyze than a linear one. Causes of nonlinearities of a cam-driven mechanical system include the complex nature of the contact region between the cam and follower, ball bearings in the follower, improper lubrication, backlash and play in certain components of the follower train, loading fluctuation, and surges in operational speeds.

Damping was at one time neglected; refined investigation necessitates its inclusion, however. All mechanical systems experience dry friction and hysteresis effects; the extent of these effects depends primarily on the number of frictional surfaces, the properties of the surface material, rheological properties of the lubricant, and the operating condition of the machine.

The cam-and-follower system containing a nonlinear power law spring -- either a stiffening or softening spring -- has been studied [29]. Coulomb damping has been used in a computer simulation of a cam-actuated soap machine [15]. A recent report [31] presents dynamic response spectra for cam-driven systems containing a mechanism that combined viscous, quadratic, coulomb, and stiction damping. An assumed-mode iteration solution technique has been proposed for solving nonlinear dynamic problems of cams [146].

High load and high speed may cause the cam-shaft wind-up phenomenon [126]. In such cases, the effect of cam shaft elasticity ought to be taken into account in modeling. The effect of cam shaft elasticity on the transient response of the follower has been simulated [19], but the effect of the flexibility of the shaft on the residual vibration of the follower was not considered. A simulation of the transient dynamic behavior of the cam-and follower system, together with its driving members, has recently been conducted [89]. A simple model was used to develop practical design rules; more complicated models, having multi-degrees of freedom, were used to predict the dynamic behavior of the system. It was concluded that the fundamental natural frequency of the system largely dominates the transient response and that the simple model is an adequate tool for predicting the amplitude of residual vibration, so far as the cam-follower-drive shaft system is concerned.

Elaborate models result in a more accurate system than do simple models but require complex mathematical solutions and modal analysis. Thus, a single-degree-of-freedom model is sometimes an oversimplification, but a highly refined model may not be economically worthwhile. For a particular machine, both validity and economy of the model must be considered.

Dynamic Response of the Follower System

In the valve gear system of an engine, vibrations excited in the valve linkage occur during both the rise and return motion stroke and also the seating of the valve after the return stroke is completed. A similar situation occurs during the dwell period in a dwell-rise-dwell cam.

In general, the vibrations excited by the first acceleration period will endure to the second if the dwell period is short and if the system is not heavily loaded and lacks effective damping. The vibrational amplitude of the first period may be reduced or reinforced by the second, depending upon the phase of vibration [6]. The peak magnitude of the acceleration of the residual vibration may be higher or lower than that of the excitation period, depending upon the shape of the excitational pulse and the natural frequency of the system.

The "response spectrum" analysis provides visualization of the effects of mechanical vibration upon a system, as well as an indication of maximum dynamic loads to various parts of the system.

The response spectrum has been used by structural dynamicists and packaging designers [17] and in studies of cam-driven systems [110 - 111]. Formulas for computing the response spectra of simple cam forms are available [60]. In 1958, a number of

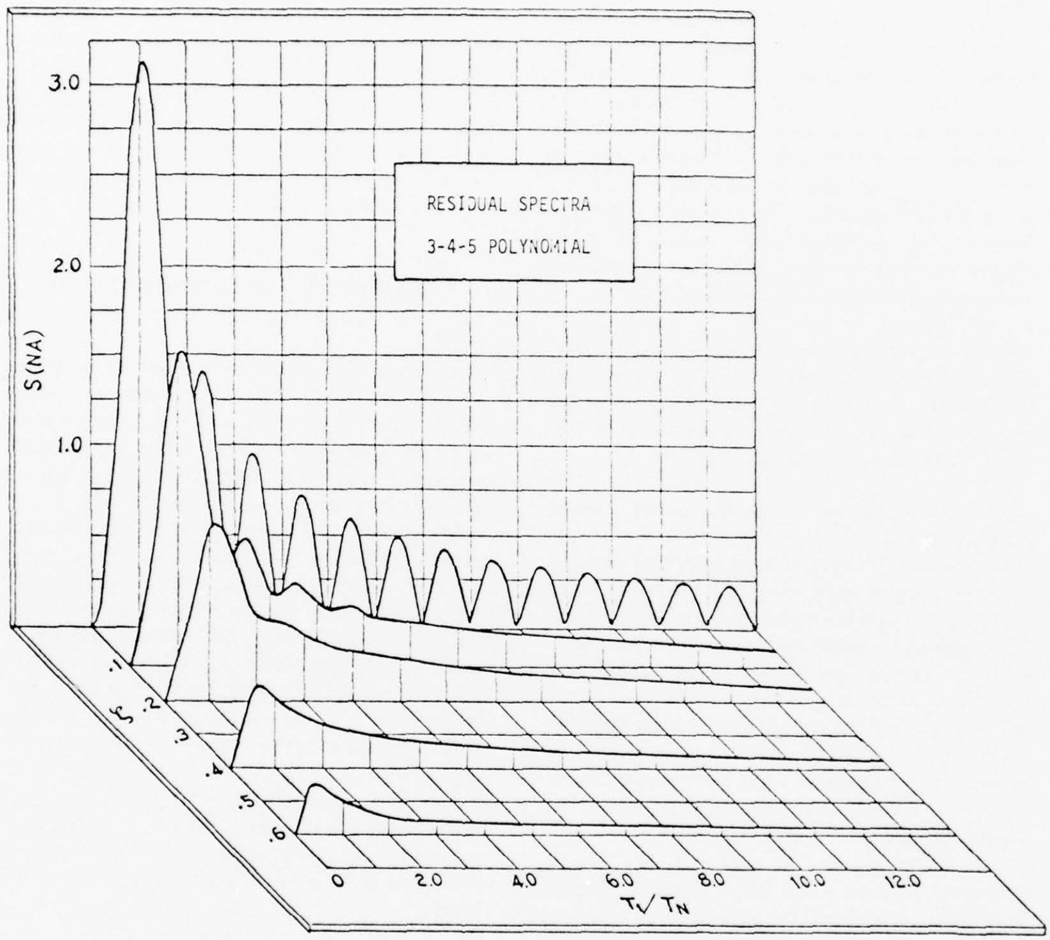

Figure 2. Damping Effect of the Residual Response of the Follower System for 3-4-5 Polynomial Cam

residual spectra for a variety of cam forms were compiled [101]; a numerical method and digital computer programming were used. The single-degree-freedom model had no damping.

In a recent study [30], a number of primary and residual response spectra for the cam-driven system were presented. The spectra corresponded to different excitations, and the damping factor was used as a variational parameter. The residual spectra were shown to be dependent upon damping values. Figure 2 is a perspective representation of normalized spectra for the 3-4-5 polynomial cam. The relationship between the normalized residual acceleration S_{NA} or $\omega_n^2 x_{max}/z_{max}$ and the dimensionless ratio T_1/T_n is plotted with damping factor ζ as a variational parameter. In a similar manner, cam-and-follower system responses to other acceleration excitations have been constructed by this reviewer.

Another convenient representation is to plot both primary and residual response spectra on four-grid log-log paper. Figure 3 is a logarithmic plot for the response of an undamped cam-and-follower system with a modified trapezoidal cam excitation.

Real Time Simlations of Cam-Follower-Driveshaft Coupled Systems

Computer simulations have been used [88] to investigate the dynamic behavior of cam mechanisms with drive shaft coupling; models up to and including four degrees of freedom have been used. The mass of the cam in the four-degree-of-freedom model is accounted for in all directions of deflection of the shaft, as is the direction of rotation, such nonlinear effects as backlash, lubricant film squeeze, and dry friction are admissible. A digital computer simulation program, "DYNACAM," has been developed for the simulation of this complex model [88].

Clearance Take-Up and Vibro-Impact Problems

The backlash between the cam and the follower result in the impact known as "cross-over shock." Cross-over shock occurs with positive drive and in adequately preloaded cams at a point where the acceleration of the follower changes sign. The intensity of impact is proportional to the peak velocity of the follower linkage. The nature of impact induced peak forces between the engaging components and their subsequent velocities has been investigated [11] with a spring-actuated, cam-and-follower model. The finite-element method [150] has been used to analyze a cam-driven valve train vibro-impact problem in which clearances may be specified.

Another transient disturbance in high-speed cam mechanisms with flexible follower is "jump," — a separation phenomenon between the follower and the cam that is caused by unbalanced forces that exceed the follower spring force during the period of negative acceleration. The prediction of follower jump and its elimination have been studied [9, 12, 59]. Data for three cam profiles -- parabolic, harmonic, and cycloidal -- are a guide for determining whether or not a basis design is susceptible to jump and for indicating the parameters that should be adjusted to correct the jump condition.

OPTIMIZATION AND COMPUTER-AIDED DESIGN

The first attempt to design the dwell-rise-dwell profile so as to minimize residual vibration over a finite range of speed based on a simple lumped spring-mass model utilized either a linear programming quadratic programming approach [91]. A method for controlling the harmonic content of the cam profile, based on a minimum mean squared error performance index over a prescribed speed range has been suggested [146-148]. A computer-assisted geometrical method for the design of a cam mechanism with oscillating roller follower has been demonstrated [135], as has the use of a sequential random search technique for determining the geometric parameters of a cam with reciprocating roller follower [32]. The spectral theory of random processes has been described for cam design optimization [130]. Other methods available in the optimal design of cam mechanisms include the synthesis of translational cams [132-134], determination of minimum size of base circle [61], and the amount of follower off-set [102].

Although computer aided design has become more important in the analysis and design of link mechanisms [154], its application to cam-driven mechanisms and systems has just begun. Applications range from simple and limited scope parameter variational studies to experimental cam-driven system synthesis and evaluations. Numerous computer programs in batch mode on cam-and-follower system analysis and component design exist, but few of

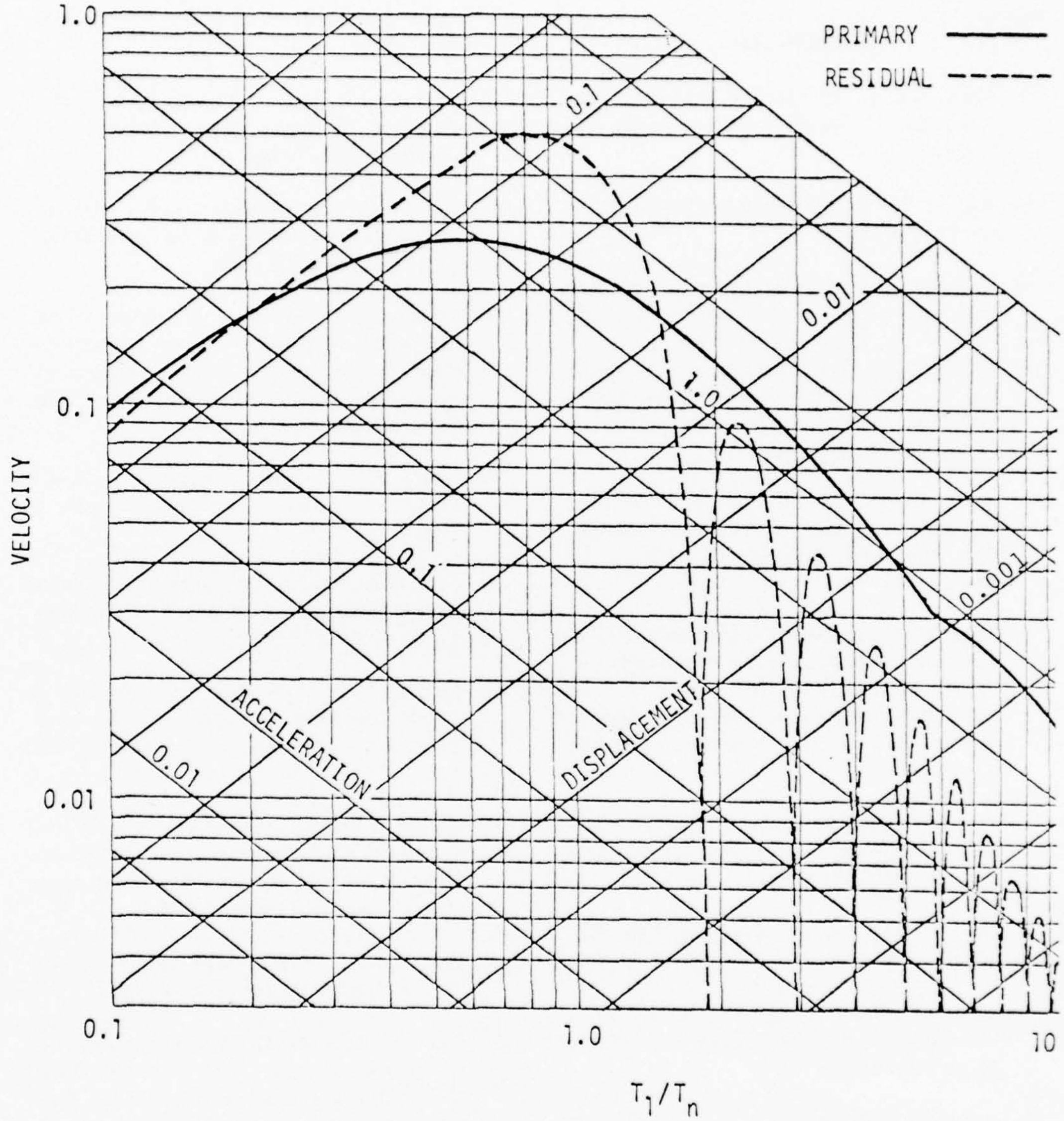

Figure 3. Tri-partite Logarithmic Representation of the Primary and Residual Response Spectra for the Modified Trapezoidal Cam

them are sophisticated. An experimental graphics cam design computer program has been developed [92]. The program can handle the kinematics of the cam and its associated follower arm and linkage but cannot handle the dynamic analysis and design. The development of a program for performing dynamic synthesis and design of the cam-and-follower system is underway.

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BOOK REVIEWS

WIND LOADING ON BUILDINGS
A. J. Macdonald
John Wiley and Sons

In his Preface the author notes that his intention was to write an undergraduate textbook that would also be useful to nonspecialist architects and engineers. In the reviewer's opinion, Macdonald succeeded admirably in both cases. The book is clearly written, well illustrated, and nicely organized. The titles of the six chapters provide a good outline of the book:

- Historical Background to the Wind Loading Problem
- Physical Properties of the Wind
- Wind Pressure Forces on Buildings
- The Design of Buildings to Resist the Wind: Wind Bracing Systems and the Calculation of Wind Forces
- Dynamics of Structures
- The Dynamic Effect of Wind on Buildings

This reviewer found relevant tidbits of "nonstandard" information in many of the chapters; e.g., the excellent tabulation of the Beaufort Scale of Wind Force in Chapter 1, the spectrum of wind speeds and their macro- and micrometeorological importance in the next chapter. All of the chapters are oriented toward physical concepts; this is of particular value in the discussion of building action and design in the fourth chapter.

There are a few minor infelicities; for example, there are no references to wind tunnel modeling nor to the work of J.E. Cernak, nor is there any reference to the ASCE - IABSE International Conference on Planning and Design of Tall Buildings. These are but minor flaws, however. Taken as a whole this is an excellent textbook, very readable, very informative, and nicely put together.

Clive L. Dym
Bolt Beranek and Newman Inc.
50 Moulton Street
Cambridge, Massachusetts 02138

METAL FATIGUE

N.E. Frost, K.J. Marsh and L.P. Pook
Oxford University Press, England (1974)

The authors, members of the staff of the National Engineering Laboratory at East Kilbride, have brought together many facets of the fatigue strength of metals and the structures made from them. The authors have interpreted data in terms of the mechanics of fatigue-crack initiation and growth. The book contains five technical chapters and six appendices. There are more than 1,000 references.

Chapter II on crack initiation includes information on surface examination, such changes in properties as hysteresis loop and damping, and surface crack initiation. Fatigue strength of plain specimens is the topic of Chapter III. High cycle fatigue and the effect of various surface finishes (electro-polish, stress relief, and forged surfaces) are described, as well as various testing methods -- reversed direct stress, reversed plain bending, and rotating bending -- and the effect of mean stress and its relationship to Goodman and Gerber diagrams. The chapter also contains information on the Von Mies theory for combined stresses and the roles of frequency effects and such environmental effects as air, vacuum, salt spray, oxygen, and water.

The effects on fatigue strength of stress concentrations and cracks comprise Chapter IV. The determination of the fatigue reduction factor (K_f) in notches, holes, and fillets and the S/N curve are discussed. The relations between K_f and K_T (stress concentration factor) are described, as are temperature and environmental effects and their role in the fatigue of notched specimens.

In Chapter V linear elastic fracture mechanics is applied to the growth of fatigue cracks. The importance of *stress intensity factors* (K_I, K_{II}, K_{III}) are introduced in a description of methods for determining and measuring fatigue crack growth rate. The reviewer would have liked an explanation of the determination of stress intensity factors by finite element methods and a more extended discussion of the Charpy impact test as it is applied to brittle fracture.

Topics of Chapter VI include low cycle fatigue, fatigue under various stress amplitudes, Palmgren-Miner's rule, effects of mechanical work on specimens, surface treatments, welded joints, programmed and random *loading, and statistical analysis of fatigue* test results. The section on low cycle fatigue could have been expanded to include more information on cyclic stress-strain representation. Chapter VI also considers random vibration, determination of important stochastic terms, cumulative damage theories, and problems of service loading.

The reviewer recommends this book to those interested in the analysis and prevention of metal fatigue.

Herb Saunders
General Electric Company
Bldg. 43, Room 319
Schenectady, New York 12345

SHORT COURSES

APRIL

INTRODUCTION TO VIBRATION AND SHOCK TESTING, MEASUREMENT, ANALYSIS AND CALIBRATION

Dates: April 11 - 15, 1977
Place: Boston, Massachusetts
Objective: Firms manufacturing weapons, aircraft, missiles, naval or military vehicle systems or components should consider sending their environmental test personnel to this seminar. This course will concentrate upon equipments and techniques rather than upon theory.

Contact: Mr. W. Tustin, Tustin Institute of Technology, Inc., 22 E. Los Olivos St., Santa Barbara, CA 93105 Tele. (805) 963-1124

RELIABILITY TESTING INSTITUTE

Dates: April 25 - 29, 1977
Place: University of Arizona, Tucson
Objective: To provide Reliability Engineers, Product Assurance Engineers and Managers and all other engineers and teachers with a working knowledge of analyzing component, equipment, and system performance and failure data to determine the distributions of their times to failure, failure rates and reliabilities; small sample size, short duration, Bayesian testing; suspended items testing; sequential testing; and others.

Contact: Dr. D. Kececioglu, Institute Director, Aerospace and Mechanical Engrg. Dept., The Univ. of Arizona, Bldg. 16, Tucson, AZ 85721
Tele. (602) 884-2495/884-3901/884-3054/884-1755

MAY

TURBOMACHINERY BLADING SEMINAR

Dates: May 3 - 5, 1977
Place: Rochester Institute of Technology, Rochester, New York
Objective: To introduce the vibration technology involved in the design and operation of turbomachinery blades. Methods and instrumentation used to measure and analyze blade vibration will be described. Industrial experts and consultants will present theoretical background material and case histories. Panel sessions dealing with gas and steam turbine blading problems and their solutions will also be conducted.

Contact: Dr. R. L. Eshleman, Director, Vibration Institute, Suite 206, 101 W. 55th St., Clarendon Hills, IL 60514 Tele. (312) 654-2254/654-2053

DIGITAL SIGNAL PROCESSING

Dates: May 10-12, 1977
Place: Philadelphia, Pennsylvania
Objective: This seminar covers theory, operation and applications -- plus additional capabilities such as transient capture, amplitude probability, cross spectrum, cross correlation, convolution coherence, coherent output power, signal averaging and plenty of demonstrations.

Contact: Mr. Bob Kiefer, Spectral Dynamics Corp. of San Diego, P.O. Box 671, San Diego, CA 92112 Tele. (714) 565-8211

FINITE ELEMENT METHOD AND NASTRAN USAGE

Dates: May 16 - June 27, 1977
Place: Washington, D.C.
Objective: A sequence of three professional development courses will be presented to provide an understanding of the technological content in general purpose finite element programs; and to provide training in the use of NASTRAN. The courses and dates are:

- Theory of Finite Elements, May 16-20, 1977
- Static Structural Analysis using NASTRAN, May 23-26, 1977
- Dynamics and Nonlinear Structural Analysis using NASTRAN, June 6 - 9, 1977.

Contact: Dr. H. Schaeffer, Schaeffer Analysis, P.O. Box 761, Berwyn Station, College Park, MD 20740 Tele. (301) 721-3788

NEWS BRIEFS

news on current and Future Shock and Vibration activities and events

NOISE-CON 77

NOISE-CON 77, the 1977 National Conference on Noise Control Engineering, will be sponsored jointly by the Langley Research Center of the National Aeronautics and Space Administration and the *Institute of Noise Control Engineering*. NOISE-CON 77 will be held at the NASA-Langley Research Center in Hampton, VA.

The three-day meeting, scheduled for 10-12 October 1977, will have as a theme "Transportation Noise," NOISE-CON 77 will cover all aspects of transportation noise including noise produced by air, highway and railway vehicles and systems, evaluation of environmental impact, propagation and attenuation of noise from vehicles, public health and welfare considerations and noise control engineering for transportation noise sources.

Eight sessions of in-depth invited papers will give attendees a complete overview of the state of transportation noise control in the United States. Particular emphasis will be placed on the following topics in three *Plenary* sessions.

- Federal Agency Transportation Noise Control Programs
- Assessment of Community Impact and Environmental Impact Statements
- Propagation of Noise from Transportation Sources
- Cost-Benefit Options in Transportation Noise Control
- Results of Concorde Noise Monitoring
- Measurement and Evaluation of Transportation Noise (including National and International Standards)

Engineers, consultants, planners, government officials, educators and all other individuals responsible for noise control will want to attend NOISE-CON 77; transportation-generated noise is a major noise source and solutions to the problem are currently being actively pursued.

More information on NOISE-CON 77 may be obtained from the Conference Secretariat, Noise Control Foundation, P.O. Box 3469, Arlington Branch, Poughkeepsie, NY 12603 - Tele. (914) 462-6719.

48TH SHOCK AND VIBRATION SYMPOSIUM MEETING ANNOUNCEMENT

The 48th Shock and Vibration Symposium will be held on October 18-20, 1977, at the Von Braun Convention Center, Huntsville, Alabama. The U.S. Army Missile Command will be the host. For information contact Henry C. Pusey, Director, The Shock and Vibration Information Center, Code 8404, Naval Research Laboratory, Washington, D.C. 20375 *Tele. (202) 767-3306.*

Key Words: Boats, Diagnostic techniques, Mechanical With definition of the requirements to be satisfied by the

ABSTRACT CATEGORIES

ANALYSIS AND DESIGN

Analogs and Analog Computation
Analytical Methods
Dynamic Programming
Impedance Methods
Integral Transforms
Nonlinear Analysis
Numerical Analysis
Optimization Techniques
Perturbation Methods
Finite Element Modeling
Modeling
Digital Simulation
Parameter Identification
Design Information
Design Techniques
Criteria, Standards, and Specifications
Surveys
Tutorial
Modal Analysis and Synthesis

COMPUTER PROGRAMS

General
Natural Frequency
Random Response
Stability
Steady State Response
Transient Response

ENVIRONMENTS

Acoustic
Periodic
Random
Siesmic
Shock
General Weapon
Transportation

PHENOMENOLOGY

Composite
Damping
Elastic
Fatigue
Fluid
Inelastic
Soil
Thermoelastic
Viscoelastic

EXPERIMENTATION

Balancing
Data Reduction
Diagnostics
Equipment
Experiment Design
Facilities
Instrumentation
Procedures
Scaling and Modeling
Simulators
Specifications
Techniques
Holography

COMPONENTS

Absorbers
Shafts
Beams, Strings, Rods
Bearings
Blades
Columns
Controls
Cylinders
Ducts
Frames
Gears
Isolators
Linkages
Mechanical
Membranes, Films, and Webs
Panels
Pipes and Tubes
Plates and Shells
Rings
Springs
Structural

SYSTEMS

Absorber
Acoustic Isolation
Noise Reduction
Active Isolation
Aircraft
Artillery
Bioengineering
Bridges
Building
Cabinets
Construction
Earth
Electrical
Foundations
Helicopters
Human
Isolation
Material Handling
Mechanical
Metal Working and Forming
Off-Road Vehicles
Optical
Package
Pressure Vessels
Pumps, Turbines, Fans, Compressors
Rail
Reactors
Reciprocating Machine
Road
Rotors
Satellite
Self-Excited
Ship
Spacecraft
Structural
Transmissions
Turbomachinery
Useful Application

77-500

Key Words: Test facilities, Modal tests

ABSTRACTS FROM THE CURRENT LITERATURE

Copies of articles abstracted in the DIGEST are not available from the SVIC or the Vibration Institute (except those generated by either organization). Inquiries should be directed to library resources. Government reports can be obtained from the National Technical Information Service, Springfield, Va., 22151, by citing the AD-, PB-, or N- number. Doctoral dissertations are available from University Microfilms (UM). 313 N. Fir St., Ann Arbor, MI. Addresses following the authors' names in the citation refer only to the first author. The list of periodicals scanned by this journal is printed in issues 1, 6, and 12.

ABSTRACT CONTENTS

ANALYSIS AND DESIGN

ANALYTICAL METHODS

77-448

Subspace Iteration Accelerated by Using Chebyshev Polynomials for Eigenvalue Problems with Symmetric Matrices

Y. Yamamoto and H. Ohtsubo
Dept. of Nav. Architecture, Univ. of Tokyo, Bunkyo-ku, Tokyo, Japan, Intl J. Numer. Methods Engr., 10 (4), pp 935-944 (1976) 2 figs, 15 refs

Key Words: Eigenvalue problems, Iteration

Bathe's algorithm of subspace iteration for the solution of the eigenvalue problem with symmetric matrices is improved by incorporating an acceleration technique using Chebyshev polynomials. This method of acceleration is particularly effective for this kind of iteration. The rate of convergence of the iteration scheme presented is considerably improved when compared with the original one, and satisfactory rates of convergence can be obtained for a wider range of eigenvalues.

77-449

Iterated Galerkin Method for Eigenvalue Problems

I. H. Sloan
Dept. of Appl. Math., Univ. of New South Wales, Sydney 2033, New South Wales, Australia, SIAM J. Numer. Anal., 13 (5), pp 753-760 (Oct 1976) 5 refs

Key Words: Eigenvalue problems, Galerkin method

The Galerkin method is compared theoretically with an iterated Galerkin method for the eigenvalue problem $y = \lambda K y$, where K is a compact linear operator (e.g. a *suitable integral operator) in a Banach space.*

STATISTICAL METHODS

(See No. 643)

VARIATIONAL METHODS

77-450

Reduction Scheme for Some Structural Eigenvalue Problems by a Variational Theorem

T.J.R. Hughes
Div. of Struct. Engrg. and Struct. Mech., Univ. of California, Berkeley, CA, Intl. J. Numer. Methods Engr., 10 (4), pp 845-852 (1976) 2 figs, 24 refs

Key Words: Eigenvalue problems, Variational methods

An accurate reduction scheme for structural eigenvalue problems is deduced from a variational theorem in which the displacement, velocity and/or momentum fields are taken to be independent.

FINITE ELEMENT MODELING

(Also see No. 484)

77-451

A Finite Element Method for Damped Acoustic Systems: An Application to Evaluate the Performance of Reactive Mufflers

A. Craggs
Dept. of Mech. Engrg., Univ. of Alberta, Edmonton, Canada, J. Sound Vib., 48 (3), pp 377-392 (Oct 8, 1976) 13 figs, 10 refs

Key Words: Mufflers, Acoustic filters, Variable cross section, Finite element technique, Variational methods

The approximate equations governing the forced harmonic motion of a damped acoustic system are set up by using a variational principle. Acoustic finite elements are then used in a computer program to study the transmission loss and insertion loss performance of some expansion chamber mufflers. The manner in which the equations are set up allows a number of input and output nodes, and two-dimensional effects involving the influence of transverse acoustic *modes to be taken into account.*

MODELING

(Also see Nos. 489, 490, 607, 628)

77-452

Eigensolution Sensitivity to Parametric Model Perturbations

C.W. White and B.D. Maytum

Martin Marietta Corp., Denver, CO, U.S. Naval Res. Lab., Shock Vib. Bull, No. 46, Pt 5, pp 123-133 (1976) 2 figs, 7 refs

Key Words: Spacecraft, Mathematical models, Eigenvalue problems, Perturbation theory

An anatomical study of the eigenproblem is pursued to find what effect a specified perturbation of a dynamic model finite element will have on analytical mode shapes and frequencies, and what dynamic model finite element perturbations are required to produce mode shapes and frequencies that satisfy design requirements or that agree with test results.

DIGITAL SIMULATION

(Also see No. 460)

77-453

Simulation of Random Environments for Structural Dynamics Testing

D.D. Styles and C.J. Dodds

National Engrg. Lab., East Kilbride, Scotland, Exptl. Mech., 16 (11), pp 416-424 (Nov 1976), 11 figs, 8 refs

Key Words: Digital simulation, Random excitation

A digital technique for the simulation of random environments is presented and the results of its application in the case of generating test signals for a simulation test on a multiwheeled road vehicle are shown.

PARAMETER IDENTIFICATION

77-454

The Experimental Determination of Vibration Parameters from Time Responses

S.R. Ibrahim and E.C. Mikulcik

NASA, Langley Research Ctr., Hampton, VA, U.S. Naval Res. Lab., Shock Vib. Bull, No. 46, Pt. 5, pp 187-196 (1976) 1 fig, 10 refs

Key Words: Modal tests, Parameter identification

This paper describes theoretical aspects and experimental verification of the application of a time domain modal vibration test technique. The theory is applicable to both lumped and distributed parameter systems. Special attention is directed to applying this technique in practice. Several application problems such as exciting the structure, minimization of measurment data, determination of the order of the mathematical model, minimization of the amount of instrumentation required and averaging of results are examined, and solutions are presented. The applicability of the technique is verified by two experiments using a cantilever beam and a rectangular plate. The case of the plate involves two very close natural frequencies which could not be identified using a frequency sweep test (peak amplitude) because of interference between modes.

77-455

Identification of Structural Modal Parameters by Dynamic Tests at a Single Point

N. Miramand, J.F. Billaud, F. LeLeux and J.P. Kernevez

Centre Technique des Industries Mecaniques SENLIS, France, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 197-212 (1976) 10 figs, 10 refs

Key Words: Parameter identification, Modal tests, Dynamic tests

The present work reported herein deals with identification, after dynamic excitation tests at a single point, of modal parameters of a structure with arbitrary viscous damping, and possibly with practically coincident frequencies of vibration. Damping values are not necessarily low and the restrictive condition that it be possible to diagonalise the damping matrix on the base of natural modes of the conservative structure is not imposed.

DESIGN INFORMATION

(See Nos. 472, 600, 601)

CRITERIA, STANDARDS, AND SPECIFICATIONS

(See Nos. 475, 515, 582)

MODE SYNTHESIS

(Also see Nos. 454, 455, 611)

77-456

Experiences in Using Modal Synthesis Within Project Requirements

J.A. Garba, B.K. Wada and J.C. Chen

Struct. and Dyn. Section, Jet Propulsion Lab., Pasadena, CA 91103, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 213-230 (1976) 9 figs, 24 refs

Sponsored by NASA

Key Words: Modal Synthesis

The paper describes the experiences in the application of modal synthesis methods to a large comples structure in a project environment. The considerations include analysis, hardware interfaces, organizational interfaces, schedules, tests, resources, and other project requirements.

COMPUTER PROGRAMS

GENERAL

(Also see Nos. 576, 591)

77-457

Sonic Boom Research, Progress Report, 1 May - 31 July 1976

V. Zakkay and L. Ting

Div. of Applied Science, New York Univ., NY, Rept. No. NASA-CR-148548, 15 pp (July 31, 1976) N76-28962

Key Words: Computer programs, Sonic boom

A computer program for CDC 6600 is developed for the nonlinear sonic boom analysis including the asymmetric effect of lift near the vertical plane of symmetry. The program is written in FORTRAN 4 language. This program carries out the numerical integration of the nonlinear governing equations from the input data at a finite distance from the airplane configuration at a flight altitude to yield the pressure signitude at ground. The required input data and the format for the output are described. A complete program listing and a sample calculation are given.

77-458

Vibration Analysis of Structures Using Fixed-Interface Component Modes

C. Szu

TRW Defense and Space Systems Group, Redondo Beach, CA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 239-251 (1976) 2 figs, 3 refs

Key Words: Computer programs, Modal analysis

This paper describes a modal coupling program (COUPL) which computes vibration modes of a structural system by using fixed-interface component modes. It contains a complete derivation of equations which lead to efficient algorithms. A sample problem to illustrate the accuracy of the formulations is also included.

77-459

A General Purpose Computer Graphics Display System for Finite Element Models

H.N. Christiansen, B.E. Brown and L.E. McCleary

Brigham Young Univ., Provo, UT, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 61-66 (1976) 8 figs, 5 refs

Key Words: Computer programs, Graphic methods, Data display, Finite element technique

This paper describes a Fortran computer program which generates displays of finite element models in line drawing and/or continuous tone format. The system reads data generated by other analysis routines, accepts a variety of control commands, and produces line drawings with (or without) hidden line removal and/or black and white or full color continuous tone images with hidden surface removal. The display features are appropriate to both static and dynamic math models and allow output in single frame or smooth animation movie format.

ENVIRONMENTS

ACOUSTIC

(Also see Nos. 451, 457, 475, 498, 526, 535, 548, 549, 550, 564, 566, 582, 597, 634, 643)

77-460

Numerical Simulation of Turbulent Jet Noise, Part 2

R.W. Metcalfe and S.A. Orszag

Flow Research, Inc., Kent, WA, Rept. No. NASA-CR-144978; Rept-62-Pt-2, 25 pp (Feb 1976)

N76-30921

Key Words: Jet noise, Digital simulation

Results on the numerical simulation of jet flow fields were used to study the radiated sound field, and in addition, to extend and test the capabilities of the turbulent jet simulation codes. The principal result of the investigation was the computation of the radiated sound field from a turbulent jet. In addition, the computer codes were extended to account for the effects of compressibility and eddy viscosity, and the treatment of the nonlinear terms of the Navier-Stokes equations was modified so that they can be computed in a semi-implicit way. A summary of the flow model and a description of the numerical methods used for its solution are presented. Calculations of the radiated sound field are reported. In addition, the extensions that were made to the fundamental dynamical codes are described. Finally, the current state-of-the-art for computer simulation of turbulent jet noise is summarized.

77-461

Jet Noise Research by Means of Shock Tubes

H. Oertel

Institut Franco-Allemand de Recherches, St. Louis, France, Rept. No. ISL-CO-209/75, 12 pp (July 2, 1975)

N76-30926

Key Words: Jet noise, Shock tube tests

A high pressure shock tube was used for studying the wave angles of straight waves emitted from cold and hot supersonic free jets. Difficulties encountered with turbulence hiding the waves were overcome by means of new visualization techniques. A simple relation was found between wave angle, jet Mach number, and sound velocity ratio which agrees well with a theoretical model.

77-462

Noise Generated by Impingement of Turbulent Flow on Airfoils of Varied Chord, Cylinders and Other Flow Obstructions

W.A. Olsen

NASA, Lewis Res. Ctr., Cleveland, OH, Rept. No. NASA-TM-X-73464; E-8829; AIAA-Paper-76-504, 36 pp (1976)

N76-30922

Key Words: Noise generation, Engine noise, Aircraft noise, Fans

Noise spectra were measured in three dimensions for several surfaces immersed in turbulent flow from a jet and over a range of flow conditions. The data are free field and were corrected to remove the small contributions of jet noise, atmospheric attenuation and feedback tones. These broadband data were compared with the results of available theories which are only strictly applicable to simple geometries over a limited range of conditions. The available theories proved to be accurate over the range of flow, chord length, thickness, angle of attack, and surface geometries defined by the experiments. These results apply to the noise generated by fixed surfaces in engine passages, the lifting surfaces of aircraft and also to fan noise.

77-463

Nonclassical Acoustics

C.P. Kentzer

School of Aeron. and Astron., Purdue Univ., Lafayette, IN, Rept. No. NASA-CR-145071; Rept-76-1, 27 pp (Aug 23, 1976)

N76-30924

Key Words: Sound transmission

A statistical approach to sound propagation is considered in situations where, due to the presence of large gradients of properties of the medium, the classical (deterministic) treatment of wave motion is inadequate. Mathematical methods for wave motions not restricted to small wavelengths (analogous to known methods of quantum mechanics) are used to formulate a wave theory of sound in nonuniform flows. Nonlinear transport equations for field probabilities are derived for the limiting case of noninteracting sound waves and it is postulated that such transport equations, appropriately generalized, may be used to predict the statistical behavior of sound in arbitrary flows.

77-464

The Prediction of Noise Levels Due to Road Traffic

M.E. Delany, D.G. Harland, R.A. Hood and W.E. Scholes
National Physical Lab., Teddington TW11 0LW, England, J. Sound Vib., 48 (3), pp 305-325 (Oct 8, 1976) 5 figs, 32 refs

Key Words: Traffic noise, Noise prediction

The authors have developed an improved procedure for predicting noise levels L_{10} from road traffic. The new method has been adopted for use within England and Wales in connection with the Noise Insulation Regulations 1975 and for other aspects of planning. The formulation of the new procedure is discussed, and its overall performance assessed by reference to a comprehensive data bank.

PERIODIC

77-465

On the Mathematical Conditions for the Existence of Periodic Fluctuations in Non-Uniform Media

M.D. Gunzburger and G.G. Kleinstein
Inst. for Computer Applications in Science and Engrg., Hampton VA 23665, J. Sound Vib., 48 (3), pp 345-357 (Oct 8, 1976) 4 figs, 7 refs
Sponsored by NASA

Key Words: Wave propagation, Periodic excitation, Periodic response

In many areas of mathematical physics where the propagation of waves through non-uniform media is of interest, it is often assumed that periodic excitations result in periodic responses. This assumption is examined by rigorously investigating the existence of periodic solutions of linear hyperbolic differential equations whose coefficients vary with position and whose solution must satisfy periodic boundary source data.

RANDOM

(See Nos. 453, 631)

SEISMIC

(Also see Nos. 479, 492, 506, 563, 596, 644, 645, 646)

77-466

Earthquake Test Environment -- Simulation and Procedure for Communications Equipment

N.J. DeCapua, M.G. Hetman and S.C. Liu
Bell Telephone Labs., Whippany, NJ 07981, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 59-67 (1976) 8 figs, 4 refs

Key Words: Seismic design, Equipment response

A rational procedure for determining a regional earthquake test environment for communications facilities is described. The approach includes examination of a wide range of telephone building responses to arrive at an upper-bound response spectra. An acceleration time history test environment in the form of a synthesized earthquake is generated to match the spectra. The regional test is then established by linearly scaling the time history to the peak acceleration shown on a national earthquake design regionalization map. Further scaling to account for motion amplification for in-building location of equipment was achieved through examination of data gathered from the 1972 San Fernando earthquake.

SHOCK

(Also see Nos. 494, 509, 510, 511, 538, 542, 574, 575, 586, 587, 592, 594, 642)

77-467

Simulation of Mechanical Shocks Environments, Volume 1

C. Lalanne
Commissariat a l'Energie Atomique, Le Barp, France, Rept. No. CEA-R-4682 (1), 470 pp (July 1975) (In French)
N76-30610

Key Words: Equipment response, Shock resistant design, Mathematical models

Shocks can produce a severe mechanical environment which must be taken in account when designing and developing new equipment. After some mathematics using Laplace and Fourier transforms, the response to a one degree of freedom system to a sinusoidal excitation is computed. This paper shows and compares different analysis methods. These methods are used to compare relative severities of tests and to establish specifications.

77-468
Simulation of Mechanical Shocks Environments, Volume 2

C. Lalanne
Commissariat a l'Energie Atomique, Le Barp, France
Rept. No. CEA-R-4682 (2), 694 pp (July 1975)
(In French)
N76-30611

Key Words: Equipment response, Shock resistant design, Mathematical models

Shocks can produce a severe mechanical environment which must be taken in account when designing and developing new equipment. After some mathematics using Laplace and Fourier transforms, the response to a one degree of freedom system to a sinusoidal excitation is computed. This paper shows and compares different analysis methods. These methods are used to compare relative severities of tests and to establish specifications.

77-469
Effect of Phase Shift on Shock Response

C.T. Morrow
Vought Corp. Advanced Technology Ctr., Dallas, TX, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 185-195 (1976) 5 figs

Key Words: Shock response, Shock tests

The effect of phase shift on shock response for an electromagnetically applied terminal step function of acceleration is studied in this theoretical investigation. It permits a theoretical investigation of effect of phase shift on response peaks and on energy absorption by a procedure that could be approximated on a laboratory shaker.

77-470
Blast Pressures Inside and Outside Suppressive Structures

E.D. Esparza, W.E. Baker and G.A. Oldham
Southwest Res. Inst., San Antonio, TX, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 197-214 (1976) 10 figs, 24 refs

Key Words: Explosion containment, Blast resistant construction

Suppressive structures are uniformly vented structures designed to remain intact under blast loads from internal explosions and are intended to attenuate the blast waves which emanate from them. This paper covers past analytical and experimental studies in explosion venting, and summarizes much of the recent blast loading work in the suppressives structures program. Scaling laws are briefly reviewed, as is the concept of an effective vent area ratio. Curve fits to external blast overpressures and impulses are given for a variety of vent panel designs, including nested angles, perforated plates, zees, louvres, and interlocking I-beams.

77-471
Analysis of Concrete Arch Magazine Using Finite Element Techniques

J.M. Ferritto
Civ. Engrg. Lab., Naval Construction Battalion Ctr., Port Hueneme, CA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 287-293 (1976) 9 figs, 2 refs

Key Words: Arches, Nuclear explosion effects, Blast resistant structures, Finite element technique

The existing standard earth-covered concrete arch igloo magazine has been analyzed using finite element techniques.

77-472
Development of Structures for Intense Ground Motion Environments

T.O. Hunter and G.W. Barr
Sandia Labs., Albuquerque, NM, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 215-225 (1976) 17 figs, 13 refs

Key Words: Underground structures, Ground motion, Nuclear explosion effects, Seismic design, Blast resistant design

The development of the technology to insure the survivability of deep buried structures subjected to short-duration, high-intensity ground motion environments requires the integration and utilization of numerous analytical techniques, design concepts, and material characterizations. Sandia Labs recently completed a program to develop a large structure designed to survive the ground motion environment resulting from a nuclear detonation in volcanic tuff. The paper details the analyses which established the characteristics of the ground motion environment and supported the structural design, the design of an experiment chamber and commensurate protective structure, and the results of the utilization of the design on an underground nuclear test.

77-473

Development of a Movable Deformable Crash Barrier

U. Seiffert and R. Weissner

Volkswagon AG, Germany, SAE Paper No. 760797, 8 pp, 12 figs, 3 refs

Key Words: Guardrails, Collision research (automotive)

Rigid moving barriers and deformable moving barriers are compared conceptually and analytically, and advantages of the deformable barrier in representing average vehicles are presented. Several physical concepts for controlled energy dissipation are described, and experimental test results given. Architecture and powerplant mass representation are discussed, and the need for field accident analysis as a basis for structural representations is stressed.

77-474

Development of a Shrapnel Containment System for Explosive-to-Electric Transducers

P.H. Prasthofer

Exxon Production Research Co., Houston, TX, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 277-286 (1976) 7 figs, 21 refs

Key Words: Explosion containment, Energy absorption

A shrapnel containment system has been developed to ensure safety of personnel and elimination of collateral damage to surrounding componentry from the operation of explosive-to-electric transducers. This has been achieved within the size and weight constraints necessary to make these devices competitive with their electronic counterparts.

GENERAL WEAPON

77-475

Prediction of Standoff Distances to Prevent Loss of Hearing from Muzzle Blast

P.S. Westine and J.C. Hokanson

Southwest Research Institute, San Antonio, TX, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 129-148 (1976) 8 figs, 11 refs

Key Words: Gunfire effects, Noise tolerance, Standards and codes

In response to MIL-STD-1474, this paper presents empirically derived equations for estimating pressure, duration, and time of arrival for reflected shocks relative to incident shocks in the blast field around the muzzle of guns.

TRANSPORTATION

(See Nos. 512, 580)

PHENOMENOLOGY

COMPOSITE

77-476

Delamination Studies of Impacted Composite Plates

C.A. Ross and R.L. Sierakowski

Univ. of Florida Graduate Engrg. Center, Eglin AFB, FL, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 173-182 (1976) 10 figs, 8 refs

Sponsored by the U.S. Army Res. Office

Key Words: Plates, Laminates, Impact response

This paper discusses both steel-epoxy and fiberglass-epoxy composite crossplied plates that were impacted with blunt ended cylindrical impactors at velocities below the critical penetration velocity. Failure mechanisms in the form of lamina delamination were observed for thirteen different types of ply arrangements.

77-477

An Evaluation of the Dynamic Characteristics of Adhesive-Elastic Anisotropic Complex Materials

S. Tokarzewski

Polish Academy of Sciences, Warsaw, Poland, 99 pp (Oct 3, 1975)

(In Polish)

N76-27367

Key Words: Composite materials, Harmonic excitation, Anisotropy

A variational method of describing the mechanical characteristics of anisotropic composites which are linearly adhesive-elastic and in a state of harmonic oscillation is formulated and used to calculate the limits for effective moduli and dynamic suppleness. The solutions are illustrated by four examples of numerical calculations of the limits of dynamic moduli calculated for two-component composites of linearly adhesive-elastic materials composed of materials with isotropic characteristics regularly anisotropic as well as transversally isotropic.

DAMPING

(Also see Nos. 451, 614)

77-478

The Measurement of Damping and the Detection of Damages in Structures by the Random Decrement Technique

J.C.S. Yang and D.W. Caldwell
Mech. Engrg. Dept., Univ. of Maryland, College Park, MD., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 129-136 (1976) 11 figs

Key Words: Damping, Crack detection, Panels, Beams, Diagnostic techniques

A technique called random decrement has been developed, which makes possible the computation of damping values and the detection of damage in structures when only response data is available. Damping ratios were computed using this technique for several modes of randomly excited panels, beams, and bones. These damping ratios compared satisfactorily to damping ratios which were computed from the power spectral density method. Standard randomdec signatures were established for all the structures. Damages were detected by observing the changes in the established signatures. Notches which simulated cracks were induced into two of the beams. The effects of these notches on the beams' signatures are presented.

77-479

An Alternate Approach to Modal Damping as Applied to Seismic-Sensitive Equipment

L.A. Bergman and A.J. Hannibal
Lord Kinematics, Erie, PA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 69-81 (1976) 7 figs, 20 refs

Key Words: Equipment response, Damping effects, Seismic excitation, Stiffness methods

The authors propose the complex stiffness approach to determine the mathematical representation and parameter identification of the influence of damping on the response of dynamic systems subjected to transient excitations such as seismic disturbances.

77-480

The Application of Elastomeric Lead-Lag Dampers to Helicopter Rotors

D.P. McGuire
Lord Kinematics, Erie, PA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 153-162 (1976) 12 figs, 5 refs

Key Words: Helicopter rotors, Elastomers, Viscoelastic damping, Mathematical models

A ground resonance analysis has been developed for fully articulated or soft in-plane helicopter rotors with elastomeric lead-lag dampers. This analysis includes a suitable mathematical model of an ideal viscoelastic material. By applying the method of multiblade coordinates, the four-degree-of-freedom analysis can be applied to any rotor with three or more blades. Stability boundaries are plotted for a hypothetical rotor system with viscous and elastomeric dampers. The nonlinear characteristics of two highly-damped elastomers were determined experimentally as functions of dynamic amplitude. The changes in the stability boundaries at various amplitudes are plotted using the measured material characteristics. The magnitude of these changes is shown to be within acceptable design limits.

77-481

Viscoelastic Damping System Use as a Remedy for POGO Effects on the DIAMANT Satellite Launch Vehicle

M. Poizat, P. Vialatoux, P. Cochery and M. Vedrenne
Societe METRAVIB - 24bis Chemin des Mouilles 69130, Ecully, France, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 245-266 (1976) 18 figs, 10 refs

Key Words: Launch vehicles, POGO effect, Viscoelastic damping

After a description of the POGO effect experienced on the French launch vehicles DIAMANT B, this paper deals with the technique of vibration damping by a viscoelastic coating and the approach which led to its implementation. In the second part, the results obtained on samples and mock-up are presented together with improvements brought by this technique to later launch vehicles.

77-482

Response Analysis of a System with Discrete Dampers

G.K. Hobbs, D.J. Kuyper and J.J. Brooks
Santa Barbara Res. Center, Goleta, CA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 137-152 (1976) 13 figs, 1 ref

Key Words: Spacecraft, Vibration damping

This paper describes the analytical design of a spaceborne structural system which limits vibrational response through the use of discrete dampers. The analytical techniques used are described, and analytical and experimental results are compared.

ELASTIC

77-483
Plane Harmonic Waves in Liquid Overlying a Monoclinic, Crystalline Layer
S. De
Old Engrg. Office (Qrs.), P.O. Santiniketan, Birbhum, West Bengal, India, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 169-179 (1976) 7 figs, 13 refs

Key Words: Rayleigh waves, Wave propagation

The boundary value problem concerning the propagation of plane harmonic waves in liquid overlying an infinite, monoclinic, crystalline layer of finite depth is solved. Solution of the frequency equation is obtained and the dispersion curves are presented. Some interesting particular cases are derived and new results are given. The results thus obtained in the case of crystalline media are clarified in constrast with an elastic isotropic case or with an orthorhombic material.

77-484
A Finite Element Computer Program for the Calculation of the Resonant Frequencies of Anisotropic Materials
W.M. Fleury
Atomic Energy of Canada, Ltd., Pinawa, Manitoba, Canada. Rept. No. AECL-5234, 62 pp (Sept 1975) N76-27604

Key Words: Anisotropy, Natural frequency, Computer programs, Finite element technique

A set of computer programs for the calculation of the flexural and torsional resonant frequencies of rectangular section bars of materials of orthotropic or high symmetry are described. The calculations are used on the experimental determination and verification of the elastic constants of anisotropic materials. The simple finite element technique employed separates the inertial field transfer matrices respectively. It includes the Timoshenko beam corrections for flexure and Lekhnitskii's theory for torsion-flexure coupling. The programs also calculate the vibration shapes and surface nodal contours or Chladni figures of the vibration modes.

FATIGUE

77-485
Fatigue Prediction for Structures Subjected to Random Vibration
W.J. Kacena and P.J. Jones
Martin Marietta Corp., Denver, CO., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 87-96 (1976) 6 figs, 10 refs

Key Words: Fatigue life, Complex structures, Random excitation

A method is presented for estimating the fatigue damage of complex structures subjected to random vibration. Conventional random vibration analysis techniques that apply specifically to normal mode analyses of lumped parameter systems are used to predict the response stress statistics. For each response stress parameter, the "apparent frequency" of response is determined and used to generate a statistical measure of the number of stress cycles in a given time. A Rayleigh distribution of stress response maxima is assumed, and the fatigue damage prediction is completed using a damage model that depends on the statistics of the random stress maxima and the number of cycles. The governing equations are presented along with an example problem which illustrates the methodology.

77-486
Mean Life Evaluation for a Stochastic Loading Programme with a Finite Number of Strain Levels Using Miner's Rule
G. Philippin, T.H. Topper and H.H.E. Leipholz
Dept. of Civil Engrg., Univ. of Waterloo, Waterloo, Ontario, Canada, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 97-101 (1976) 2 figs, 13 refs

Key Words: Fatigue life, Fatigue (materials), Stochastic processes

This paper is concerned with fatigue life prediction of a material subjected to a stochastic loading programme. Using Miner's rule - recognized to be valid from a probabilistic point of view, - together with a damage parameter associated with each closed hysteresis loop defined in the stress-strain diagram corresponding to the given loading programme, an example of life prediction is presented.

77-487
Analysis of Fatigue Under Random Vibration
R.G. Lambert
Aircraft Equipment Div., General Electric Co., Utica, NY 13503, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 55-72 (1976) 16 figs, 14 refs

Key Words: Fatigue life, Random vibration, Equipment response

Closed form analytical solutions have been derived to quantitatively describe many areas of interest regarding fatigue under random vibration. These areas include relating root-mean-square Gaussian stress to cycles and time to failure, the probability density function of cycles to failure, and the probability of failure to cycles to failure. Also included are the effects of stress limiting and of an endurance limit. Comparisons between analytical predictions and empirical results have been shown to be good whenever such comparisons were made.

77-488
Random Vibration Fatigue Tests of Weldbonded and Bonded Joints
F. Sandow, Jr. and O. Maurer
Air Force Flight Dynamics Lab., Wright-Patterson AFB, OH., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 73-85 (1976) 24 figs, 11 refs

Key Words: Joints, Fatigue tests, Random vibration

This paper presents the results of a series of random shaker experiments, which were conducted with test articles consisting of thin beams, fastened to a simulated stiffener by the weldbond process, using a so-called spot-weld etch surface preparation treatment, and similar test articles manufactured by the metal bond process, using a metal bond (FPL) etch surface preparation. The test procedure is discussed. To establish base line data, a series of riveted samples of the same basic dimensions were also tested. Fatigue curves in the range of 10^5 to 10^8 cycles were established for skin thicknesses of .032 inch and .040 inch for each of the three joint constructions. Results are also compared to fatigue data obtained elsewhere.

FLUID

(See Nos. 525, 535, 555)

SOIL

77-489
The Vibrations in Construction Equipment
P.A. Drakatos
Inst. of Technology, Univ. of Patras, Patras, Greece, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 49-55 (1976) 2 figs, 22 refs

Key Words: Soil compacting, Vibrators (machinery), Interaction: soil-structure, Mathematical models

Where construction equipment are used, such as vibrating compactors, best soil compaction is achieved by the appropriate combination of the operation frequency and the vibration amplitude of the vibrating roller. In this process the propagation speed of the longitudinal waves created on soil during the operation of compactor is a function of the frequency and vibration amplitude. In the field, the above parameters are measured with great accuracy by means of a Laser device. In practice, the stochastic model for construction equipment - soil system can be determined with a very good approximation if the various soil parameters are taken into consideration in the design of the machines.

77-490
Model of Soil - Vibrating Machine
P.A. Drakatos
Inst. of Technology, Univ. of Patras, Patras, Greece, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 57-60 (1976) 1 fig, 5 refs

Key Words: Soil compacting, Vibrators (machinery), Interaction: soil-structure, Mathematical models

During soil compaction by means of vibrating machinery changes in the density of the soil affect changes in the damping and elastic characteristics of the soil. The calculation of the compaction force applied in the process is difficult. Up to now this force has been estimated experimentally. By means of a Laser device capable of measuring the frequency and the amplitude of the vibrations of the vibrating machine, the compaction force can be calculated.

77-491
Dynamic Response of Rigid Foundations of Arbitrary Shape

H.L. Wong and J.E. Luco
Earthquake Engrg. Res. Laboratory, California Inst. of Technology, Pasadena, CA., Intl. J. Earthquake Engr. Struc. Dynam., 4, pp 579-587 (1976)

Key Words: Interaction: structure-medium, Foundations

An approximate numerical procedure for calculation of the harmonic force-displacement relationships for a rigid foundation of arbitrary shape placed on an elastic half-space is presented. This procedure is used to evaluate the vertical, rocking and horizontal compliance functions for rigid rectangular foundations and the vertical compliance for a rigid square foundation with an internal hole. Several comparisons between the results obtained by the proposed approach and other methods are also presented.

77-492
Nonlinear Behavior in Soil-Structure Interaction
E. Kausel, J.M. Roesset and J.T. Christian
Stone & Webster Engrg. Corp., Boston, MA., ASCE J. Geotech. Engr. Div., 102 (GT11), pp 1159-1170 (Nov 1976)

Key Words: Interaction: soil-structure, Seismic excitation, Earthquakes

The relative importance of secondary nonlinear effects in soil-structure interaction are investigated by means of the iterative linear method. It is found that the refinement in the analyses, while increasing the cost of computation several times, does not change the dynamic response in the structure to a significant degree. At the same time, an improved algorithm is presented for the computation of the characteristic strain used in the iterative approach.

77-493
Dynamic Shear Moduli for Dry Sands
M.A. Sherif and I. Ishibashi
Dept. of Civ. Engrg., Univ. of Washington, Seattle, WA., ASCE J. Geotech. Engr. Div., 102 (GT11), pp 1171-1184 (Nov 1976)

Key Words: Dynamic shear modulus, Sands

Using the Torsional Simple Shear Device, the writers investigated the relationship between the equivalent dynamic shear moduli, G_{eq} and shear strain γ for Ottawa sand, Del Monte sand, Golden Gardens, and Seward Park sands. Based on their experimental findings, the writers propose two equations relating shear moduli to shear strain (below and above 0.03%) as a function of the soil angle of internal friction ϕ and the effective confining pressure σ_c. Also, a relationship is proposed that considers the effects of the number of stress cycles on equivalent shear moduli. A nomograph is proposed to assist in the easy determination of equivalent shear moduli for sands. A comparison is made between these findings and the results of previous researchers.

77-494
Analysis of Explosively Generated Ground Motions Using Fourier Techniques
S.E. Blouin and S.H. Wolfe
U.S. Army Cold Regions Res. and Engrg. Lab., Hanover, NH., Rept. No. CRREL 76-28, 91 pp (Aug 1976)
Sponsored by the U.S. Air Force Weapons Lab.

Key Words: Fourier techniques, Fourier transformation, Ground motion, Nuclear explosions, Underground explosions

Fourier transforms of selected ground-motion time histories from five underground high-explosive and nuclear detonations are used to define the transmission properties (transfer functions) of three rock types. Absorption, a measure of a rock's energy dissipating characteristics, is expressed for each of the tests as a function of the frequency of transmission. Dispersion results from a variation in transmission velocity with frequency and is described for each test by a phase velocity spectrum. The transmission properties from one of the sites are used to predict a ground-motion time history at that site from another nuclear event. The potential use of Fourier techniques to make ground-motion predictions and to measure in-situ material properties is discussed.

VISCOELASTIC
(See No. 481)

EXPERIMENTATION

DIAGNOSTICS
(Also see Nos. 478, 584)

77-495
Mechanical Impedance Techniques in Small Boat Design
B.E. Douglas and H.S. Kenchington
David W. Taylor Naval Ship R & D Center, Annapolis Lab., Annapolis, MD 21402, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 107-116 (1976)
8 figs, 8 refs

Key Words: Boats, Diagnostic techniques, Mechanical impedance

This paper is concerned with the use of mechanical impedance technology to isolate and diagnose the structural cause of airborne-noise problems on small boats. A normal mode interpretation is given to analog mechanical impedance and structural radiation factor spectra in order to identify hull and decking resonances, examine noise transmission path strengths, and differentiate between radiating structural modes and the normal acoustic modes of the room. These techniques were applied to solve an airborne-noise problem on a 36-foot high performance naval landing craft.

FACILITIES

77-496

Design Study of an Experimental Blast Chamber

W.E. Baker and P.A. Cox

Southwest Research Institute, San Antonio, TX., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 227-250 (1976) 5 figs, 31 refs

Key Words: Test facilities, Blast effects

This paper covers the preliminary design considerations for *an experimental blast chamber* intended for repetitive firings of explosive charges up to 13.61 kg in weight, with minimal disturbance to personnel in the vicinity. It includes a survey of past work in blast chamber design, the evaluation of several alternate design concepts and the results of analyses performed to establish chamber material, spherical or cylindrical shape, size and thickness. Responses to initial and reflected blast waves are included, as well as stresses from internal static pressures. Effects of chamber evacuation on modification of loading and chamber stresses are shown. Other factors addressed in the paper are chamber venting for unevacuated chambers, responses to charges detonated off-center, lining with shock-absorbing materials, and spalling effects.

77-497

A Test Facility for Aircraft Jet Noise Reduction. Part II

B.L. McGehee

Boeing Commercial Airplane Co., J. Environ. Sci., 19 (5), pp 20-24 (Sept/Oct 1976) 2 figs, 24 refs

Key Words: Aircraft noise, Noise reduction, Test facilities

With definition of the requirements to be satisfied by the LTC, design development was found to logically fall into three categories: Acoustics, Aerothermodynamics, and Community Noise. Areas of design other than these pertain to the various support systems such as data (measurement, recording, and processing) and mechanical (fuel supplies, laboratory air, cooling water, etc.). The mechanical, electrical and structural considerations are state-of-the-art and, although many innovations have been incorporated in the facility, development testing was not required.

77-498

Thermo-Acoustic Simulation of Captive Flight Environment

W.D. Everett

Pacific Missile Test Center, Point Mugu, CA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 103-112 (1976) 6 figs, 2 refs

Key Words: Test facilities, Flight simulation, Acoustic excitation, Thermal excitation, Missiles

A test facility and procedure have been developed wherein the combined thermal and vibration stresses of captive flight are accurately simulated. The facility is essentially a large reverberant acoustic chamber within which is a small temperature chamber or shroud. The flexibility of the thermal shroud is the novel feature of the facility wherein it contains the temperature conditioning air to the immediate vicinity of the test missile, yet it is transparent to the acoustic energy which induces the vibration in the missile. The test procedure is based on an estimate of the lifetime flight-use environment for the tested missile in terms of percentage of life at various flight dynamic pressure conditions.

77-499

A Three Directional Vibration System

F.M. Edgington

Dynamic Environments Branch, Applied Sciences Div., White Sands Missile Range, NM., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 15-26 (1976) 35 figs

Key Words: Test facilities, Flight simulation, Vibration tests

The design and performance of a three directional vibration system to simulate ground and air transportation vibration environments is presented. The basic system was built at White Sands Missile Range, New Mexico and utilizes a multi-axis drive unit.

77-500
Dual Shaker Vibration Facility

C.V. Ryden
Pacific Missile Test Center, Point Mugu, CA., U.S.
Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 27-53 (1976) 37 figs, 15 refs

Key Words: Test facilities, Vibration tests, Shakers, Missiles

Two complete and independent vibration systems were utilized to test the PHOENIX and HARPOON missiles - including random noise generators, equalizers, amplifiers and shakers. Since the signals from the two systems are random and independent there is no constant phase relation (continuously and randomly changing) between the two vibration inputs and their respective transmissibility through the missile. The shakers are therefore independently controlled assuming the system is essentially linear at the critical frequencies and amplitudes. The two shakers were identical in order to reduce setup complication and control problems.

77-501
A Data Acquisition Method for Dynamic Vehicle Testing

J.C. Abromavage and R.L. Beemer
Amerco Technical Center, SAE Paper No. 760789, 12 pp, 10 figs

Key Words: Automobiles, Motor vehicles, Dynamic tests, Test equipment, Test facilities

This paper discusses the development and construction of a Mobile Telemetry Instrument Facility (MTIF) used for the acquisition of dynamic vehicle test data. Objectives of the MTIF are maximum flexibility, high accuracy, and fast response during dynamic test activities. The latest data telemetry, recording and reduction technology is incorporated in the facility. Selection and application of the instrumentation such as light beam oscillographs, Mecca or floating ground systems, environmental control, on-line data analysis and instrument calibration equipment are explained. Also covered are the advantages of such a mobile facility over a permanent operation base.

77-502
MODALAB - A New System for Structural Dynamic Testing

R.C. Stroud, S. Smith and G.A. Hamma
Space Systems Div., Lockheed Missiles & Space Co., Sunnyvale, CA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 153-175 (1976) 26 figs, 6 refs

Key Words: Test facilities, Modal tests

The subject of this paper is the MODALAB (Mobile Dynamic Analysis Laboratory). Objectives of the MODALAB development are discussed. The theoretical concepts supporting the current MODALAB modal-test procedures are outlined along with alternate testing theories. The MODALAB hardware and software systems are described. There is a delineation of the current modal-test procedure. Results of an early application are presented.

77-503
An Introduction to the Application of Modal Analysis Surveys in the Test Laboratory

H. Caruso
Product Qualification Lab., Westinghouse Electric Corp., Baltimore, MD., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 253-256 (1976)

Key Words: Modal analysis, Test facilities

This paper provides basic guidelines for performing effective modal analyses in the test laboratory. Considerations for appropriate accelerometer placement and significant recording equipment characteristics are detailed. The unique flexibility of modal analysis test fixturing is discussed along with specific test practices that should be employed to ensure the acquisition of uncontaminated modal information. Finally, the use of animated displays to interpret modal data is presented with special attention given to display utility and limitations.

INSTRUMENTATION

(Also see No. 509)

77-504
Noise Dosimeters -- Past, Present and Future

D.A. Giardino and J.P. Seiler
Mining Enforcement and Safety Administration, Pittsburgh, PA., S/V Sound Vib., 10 (10), pp 26-30 (Oct 1976) 9 figs

Key Words: Noise measurement, Measuring instruments

The technical criteria for noise exposure rating, the development of noise dosimeters, and practical requirements for these instruments are detailed. Commercially available units are briefly described and the future importance of noise dosimeters is evaluated.

77-505

The Effect of Signal Clipping in Random Vibration Testing

A.G. Ratz

Vibration Instruments Co., Anaheim, CA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 113-127 (1976) 11 figs, 7 refs

Key Words: Vibration tests, Test equipment, Electrodynamic shakers

The effect of clipping the drive voltage is considered, when an electrodynamic exciter is used to carry out wide-band random tests. The theory is derived for the clipping influences of force capacity of the system.

77-506

Barrel-Tamped, Explosively Propelled Plates for Oblique Impact Experiments

F.H. Mathews and B.W. Duggin

Sandia Laboratories, Albuquerque, NM 89115, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 145-154 (1976) 8 figs, 9 refs

Key Words: Plates, Impact tests, Test equipment

The use of explosively driven rotating flyer plates for high-velocity impact fuze testing involves the detonation of a solid explosive to accelerate massive, slowly rotating plates to high velocities. The device to be tested is positioned at a distance along the flight path sufficient to allow rotation of the flyer plate before impact. Thus, any angle between the plate's surfaces and the plate velocity vector can be obtained.

77-507

Dynamic Response of Flexible Urethane Foam After Stress-Relaxation

W.A. Ashe

BASF Wyandotte Corp., Geismar, LA, SAE Paper No. 760727, 8 pp, 2 figs

Key Words: Test equipment, Dynamic response, Foams

This paper describes the development of a mechanical test apparatus for measuring the dynamic response of flexible foams after extended stress relaxation. Additional items discussed are creep, pocketing and fight back.

77-508

Simulating Tactical Missile Flight Vibration with Pneumatic Vibrators

D.G. VandeGriff, W.D. Ayers and J.G. Maloney

General Dynamics Corp., Pomona, CA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 1-14 (1976) 14 figs

Key Words: Pneumatic equipment, Vibrators (machinery), Flight simulation, Missiles

The use of multiple pneumatic vibrators for the simulation of simultaneous three axis broadband random flight vibration is presented for a tactical missile application. The acceleration spectral densities measured during the pneumatic vibration test compare favorably with those telemetered during flight of the tactical missile.

SIMULATORS

(Also see Nos. 499, 500, 599)

77-509

Actuator Development for System-Level Shock Testing

G.R. Burwell

Boeing Aerospace Co., Seattle, WA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 85-99 (1976) 13 figs, 8 refs

Key Words: Shock tests, Nuclear explosion simulation

This paper discusses the design, development and capability of an actuator for system-level shock testing. The actuator was designed to provide input motions to a full-scale test article that simulate the airblast-induced ground motion associated with nuclear attack. The actuator energy source is high-pressure gaseous nitrogen which powers a piston/piston rod connected to a test article. Piston motion is controlled by the flow of hydraulic fluid through piping, accumulators and orifice plates. The design requirements are presented including the wide range of shock levels which the actuator was required to produce. The design approach and the influence of the dynamic response model on the design are discussed. A description of the model, model refinements and improved coefficient values obtained empirically also is presented. Typical test/analysis comparisons of motion histories are provided. A description of the actuator physical operation is provided with an emphasis on configuration elements that control the motion and thus determine the input conditions to the test article.

77-510

Review of Nuclear Blast and Shock Environment Simulation

E. Sevin

Defense Nuclear Agency, Washington, D.C., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 5-16 (1976) 10 figs

Key Words: Nuclear explosion simulation, Testing techniques

An overview is presented of nuclear airblast, cratering, and ground shock environment simulation techniques utilizing conventional high explosives and suitable for large-scale field testing. State-of-the-art capabilities for both full space and limited space simulation are discussed, including the so-called MINE THROW and HEST techniques. Representative data are shown to indicate the degree of the simulation possible in airblast, crater shapes, and ground motions for both the kiloton and megaton range of near surface nuclear explosions.

77-511

Design of a Blast Load Generator for Overpressure Testing

P. Lieberman, J. O'Neill, D. Freeman and A. Gibbs

TRW Defense and Space Systems Group, Redondo Beach, CA 90278, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 261-276 (1976) 10 figs, 2 refs

Key Words: Blast loads, Nuclear explosion simulation, Computer programs

This paper discusses the requirements and design features of a blast load generator which can essentially simulate the overpressure history of an atomic weapon burst in a 7-ft diameter and 9-ft high test volume. The overpressure history parameters, rise time to peak pressure, peak pressure and pressure pulse decay time, are considered in the design of the blast load generator parameters, inert driver gas and pressurization, driver section cross-sectional area and volume, driver section vent hole and time delay, driven section cross-sectional area and volume, and filling materials and their layered depths. A computer code prediction of environment performance prior to construction of the blast load generator, as well as the measurements of the performance, are both presented

TECHNIQUES

(Also see Nos. 510, 562, 577, 619, 630)

77-512

Development and Application of a Miniature Recorder/Analyzer for Measurement of the Transportation Environment

M.A. Venetos and J.J. Lorusso

Air Force Packaging Evaluation Agency, Wright-Patterson AFB, OH., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 23-29 (1976) 13 figs

Key Words: Measurement techniques, Transportation effects

This paper describes the design of a miniature recorder/analyzer system developed primarily for the measurement of the environment experienced by packaged items during handling, shipment, and storage. Significant features of this solid state device are: real time data analysis, metal oxide semiconductor memory, small size, low power requirements, rugged construction, and extensive measurement capability. Environmental parameters measured include impact shock, temperature and humidity. Applications of the recorder are described for monitoring shipments of cushion packs, jet engines, and nuclear cargo.

77-513

Dynamic Measurement of Low-Frequency Components of Track-Induced Railcar Wheel Accelerations

S.A. Macintyre, C.T. Jones and K.E. Scofield

ENSCO, Inc., Springfield, VA 22151, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 11-21 (1976) 9 figs

Key Words: Railroad cars, Accelerometers, Railroad tracks, Vibration measurement, Measurement techniques

This paper describes how a limited range high-resolution servo-accelerometer can be used in railcar applications. The development of the system transfer function, a description of the physical system, and laboratory test results are also discussed.

77-514
Bounded Impact - A Repeatable Method for Pyrotechnic Shock Simulation
R.T. Fandrich, Jr.
Harris Electronic Systems Div., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 101-107 (1976) 9 figs, 14 refs

Key Words: Testing techniques, Pyrotechnic shock environment

A method to simulate pyrotechnic shock occurrences is described in this paper. The method is capable of simulating shock levels up to 20,000 G spectra, is repeatable with no residual displacement or velocity, and produces time histories similar to field events. A parametric study was performed on a computer model of the technique and a comparison is made of model prediction versus actual results.

77-515
Standards for Noise Measurement
R.W. Heymann and F.Z. Sachs
U.S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD., S/V Sound Vib., 10 (10), pp 14-20 (Oct 1976)

Key Words: Noise measurement, Measurement techniques, Standards

A compendium of some of the recent noise measurement standards is presented and comparisons of the standards are made according to approaches taken in the above factors. The discussion of the various approaches should provide some assistance in the drafting of new or revised standards.

COMPONENTS

BEAMS, STRINGS, RODS

77-516
On the Solution of the Inverse Problem with Amplitude and Natural Frequency Data. Part 1
V. Barcilon
Dept. of Geophysical Sciences, Univ. of Illinois, Chicago, IL., 24 pp (June 1976)
AD-A028 776/3GA

Key Words: Beams, Earthquakes

A procedure is presented for finding the elastic properties of a vibrating body. The data needed to insure a unique solution are contained in the impulse response. Thus both amplitude and natural frequencies are required. The particular case of a beam is used to illustrate the procedure.

77-517
Power Series Expansion of the Dynamic Stiffness Matrix Including Rotary Inertia and Shear Deformation
M. Paz and L. Dung
Univ. of Louisville, Louisville, KY., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 181-184 (1976) 1 fig, 7 refs

Key Words: Beams, Timoshenko theory, Rotary inertia effects, Transverse shear deformation effects, Stiffness methods

The dynamic stiffness matrix for a beam element is derived from the Timoshenko differential equation with the inclusion of rotary inertia and a shear deformation. The terms of this matrix are expanded into a power series as a function of the vibrating frequency. A discussion is presented for establishing the region of convergence of the series expansion.

77-518
Analysis of Space Frameworks Containing Curved Beams
M.A. Cassaro and M. Paz
Univ. of Louisville, Louisville, KY., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 37-48 (1976) 16 figs, 2 refs

Key Words: Curved beams, Frames, Transfer matrix method

This paper presents a study of the analysis of curved beams in space by use of the transfer method. The analysis is capable of handling beams having additional distortions such as built-in twist with respect to the longitudinal axis, as well as coordinate transformations producing super-elevation and inclination of the beam axis. Comparisons are made between internal forces produced in straight beams and curved beams to evaluate the effects of beam curvature and the additional distortions of built-in twist, super-elevation and beam inclination.

77-519
Dynamic Response of Electrical Cables to Shock Motion
R.W. Doll
TRW Defense and Space Systems Group, Redondo Beach, CA 90278, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 109-120 (1976) 7 figs, 2 refs

Key Words: Cables, Equations of motion

The response for flexible cables is derived in terms of the longitudinal, torsional and two-transverse equations of motion. An investigation of the cable response is accomplished using a finite element discretization of the equations of motion.

77-520
Dynamics of Flexible Cables Under Combined Vortex and Parametric Excitation
S.A. Trogdon, J.F. Wilson and B.R. Munson
Duke Univ., Durham, NC., J. Dyn. Syst., Meas. and Control, Trans. ASME, 98 (3), pp 286-290 (Sept 1976) 6 figs, 9 refs
Paper No. 76-Aut. KK

Key Words: Cables, Transient response, Vortex shedding, Parametric excitation

The response of a flexible cable under the combined effects of transverse fluid loading (vortex shedding) and parametric excitation (time varying tension) is considered. Experimental results are presented for steady-state cases.

BEARINGS

77-521
Spherical Plain Bearings -- Friction, Wear, and Service Life
W.M. Spitzig
Ina Bearing Co., Inc., SAE Paper No. 760707, 16 pp, 21 figs

Key Words: Bearings, Dynamic response

A new calculating method has been developed which allows the designer to predict more accurately the service life of radial spherical plain bearings. Part I covers relubricable steel-on-steel bearings, and Part II covers self-lubricating PTFE-on-chromium or PTFE-on-stainless steel bearings.

BLADES

77-522
Elementary Three-Dimensional Interactive Rotor Blade Impact Analysis
R.W. Cornell
Applied Mechanics and Aerodynamics, Hamilton Standard Div. of United Technologies Corp., Windsor Locks, CT., J. Engr. Power, Trans. ASME, 98 (4), pp 480-486 (Oct 1976) 14 figs, 8 refs
Paper No. 75-WA/GT-15

Key Words: Blades, Fans, Impact response (mechanical), Mathematical models, Mass-spring systems

A theoretical analysis is presented which defines the loading and response of a rotor fan blade due to soft or frangible impacts in terms of the three fundamental modes of vibration by representing the blade as a lumped, spring-mass system. The features, solution, program, and applications of this analysis are reviewed, and the results are compared with those from a number of blade and specimen tests and found to be in good agreement.

COLUMNS

77-523
Evaluation of Resonant Column Test Devices
G.R. Skoglund, W.F. Marcuson, III and R.W. Cunny
U.S. Army Engr. Waterways Experiment Station, Vicksburg, MS., ASCE J. Geotech. Engr. Div., 102 (GT11), pp 1147-1158 (Nov 1976)

Key Words: Columns (supports), Dynamic modulus of elasticity, Dynamic tests, Sand

Resonant column tests were performed by six participants in a program designed to evaluate results from various devices. Each participant was given more or less identical samples of material and specific instructions intended to keep the test conditions as near identical as possible. Differences in shear and compression moduli ranged from minus 19% to plus 32% of the average. These differences could be explained largely by differences in unit weight and specimen preparation techniques. No systematic differences were noted because of differences in apparatus used.

CYLINDERS

77-524

Noise Measurements of the Lowest Frequency Longitudinal Mode of an Aluminum Cylinder at Liquid Nitrogen Temperatures. Final Report

W.S. Davis

Dept. of Physics and Astronomy, Maryland Univ., College Park, MD., 24 pp (1976)

AD-A029 046/0GA

Key Words: Noise measurement, Cylinders

The lowest frequency longitudinal mode of an aluminum cylinder has been studied over the temperature range 60K - 78K. Lead zirconate titanate crystals were bonded to the cylinder for observation of the thermal fluctuations, and relaxation phenomena. The very large fluctuations in noise temperature are not understood and warrant further investigation.

77-525

Forces on Cylinders Near a Plane Boundary in a Sinusoidally Oscillating Fluid

T. Sarpkaya

Dept. of Mech. Engrg., Naval Postgraduate School, Monterey, CA., J. Fluids Engr., Trans. ASME, 98 (3), pp 499-505 (Sept 1976) 5 figs, 13 refs

Paper No. 76-FE-K

Key Words: Cylinders, Pipelines, Fluid-induced excitation

The in-line and transverse forces acting on circular cylinders placed near a plane boundary in a sinusoidally oscillating fluid in a U-shaped vertical water tunnel have been measured. The period parameter U_mT/D, the Reynolds number and the gap between the cylinder and the plane boundary were varied.

DUCTS

(Also see Nos. 588, 589)

77-526

Duct Wall Impedance Control as an Advanced Concept for Acoustic Impression. Final Report

P.D. Dean and B.J. Tester

Lockheed-Georgia Co., Marietta, OH., Rept. No. NASA-CR-134998, LG76ER0132, 364 pp (Nov 1975)

N76-30028

Key Words: Ducts, Acoustic linings, Acoustic impedance

Models and tests on an acoustic duct liner system which has the property of controlled-variable acoustic impedance are described. This is achieved by a novel concept which uses the effect of steady air flow through a multi-layer, locally reacting, resonant-cavity absorber. The scope of this work was limited to a 'proof of concept.' The test of the concept was implemented by means of a small-scale, square-section flow duct facility designed specifically for acoustic measurements, with one side of the duct acoustically lined.

77-527

Comparison of Cross-Spectral and Signal Enhancement Methods for Mapping Steady-State Acoustic Fields in Turbomachinery Ducts

J.W. Posey

NASA, Langley Res. Center, Langley Station, VA., Rept. No. NASA-TM-X-73916, 14 pp (Aug 1976)

N76-30030

Key Words: Ducts, Turbomachinery, Sound pressure

The conceptual differences between the following two approaches used to measure spatial variations in steady-state acoustic pressure amplitude were examined: taking the cross spectrum between two signals from probes in the same field or taking the difference in complex Fourier transform of enhanced probe signals. Conditions for equivalence of the two methods are discussed.

GEARS

77-528

Vibrations in Gear Drives; Test Results and Calculation Method for Dynamic Tooth Forces

H. Rettig

Royal Aircraft Establishment, Farnborough, England, Rept. No. RAE-Lib-Trans-1882; BR52720, 18 pp (Feb 1976) (Engl. transl. from 4th World Congr. on the Theory of Machines and Mech., Paper 30, 1975, pp 163-168)

N76-27576

Key Words: Gear drives, Vibration response

In order to determine the vibrational forces and the stability of vibrations in a gear assembly, the effect of disturbance factors on the behavior of viscoelastic vibration systems must be known. The extent to which the idealization of such a system is possible without suppression of the important characteristics of the solution is considered. Based on test results and theoretical investigations, a simplified calculation for the determination of the dynamic forces on the teeth is developed.

ISOLATORS

77-529

Focalization of Semi-Symmetric Systems

A.J. Hannibal

Lord Kinematics, Erie, PA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 253-267 (1976) 7 figs, 10 refs

Key Words: Isolators, Mass-spring systems

The focalization of a rigid body having one plane of symmetry and supported by a rigid foundation through four axisymmetric isolators is investigated. The isolators are divided into two sets having different elevations and lateral spreads. The existence of multiple solutions and the sensitivity of the focalization to parameter variations are discussed.

77-530

Matrix Methods for the Analysis of Elastically Supported Isolation Systems

G.L. Fox

Barry Div., Barry Wright Corp., Burbank, CA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 135-145 (1976) 3 figs, 7 refs

Key Words: Isolators, Mass-spring systems

This paper presents a new method for calculating stiffness, damping and inertia matrices for lumped parameter linear systems. After a discussion of the solution to the equations for a six degree of freedom rigid body, the analysis is extended to a two-mass, twelve degree of freedom system. In the limiting case that the second mass inertia matrix can be ignored, some especially simple relationships are obtained.

LINKAGES

(See No. 488)

MECHANICAL

77-531

Dynamic Characteristics of Contact-Separation in Mechanisms

Y.R. Chang and F.Y. Chen

State Univ. of New York at Buffalo, Buffalo, NY., ASME Paper No. 76-DET-14

Key Words: Mechanical elements, Mechanisms, Viscous damping, Coulomb friction

An analytical study of the contact-separation phenomenon of two pre-loaded mechanical members subjected to an external motion excitation through the supporting frame is presented.

PIPES AND TUBES

(Also see No. 525)

77-532

Vibration and Stability of Fluid-Conveying Pipes

H. Lin and S. Chen

Argonne National Lab., Argonne, IL 60439, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 267-283 (1976) 15 figs, 5 refs

Key Words: Pipes (tubes), Fluid-induced excitation, Stability, Mathematical models

The dynamics of a fluid-conveying pipe, clamped at the upstream end and elastically supported at the downstream end, are studied and applied to the special case of an LMFBR steam generator tube. The method presented can accurately predict the response of a system to an excitation with an arbitrary initial condition and time-dependent boundary condition. The method can be applied to other nonconservative systems.

PLATES AND SHELLS

(Also see Nos. 555, 639)

77-533

Fragment Velocities from Bursting Cylindrical and Spherical Pressure Vessels

R.L. Bessey and J.J. Kulesz
Southwest Research Institute, San Antonio, TX, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 251-259 (1976) 7 figs, 9 refs

Key Words: Containment, Pressure vessels

An analytical method is used to describe bursting gas reservoirs and to predict the maximum fragment velocity attained by pieces from the fragmenting containment vessels.

77-534

Computation of Upper and Lower Bounds to the Frequencies of Clamped Cylindrical Shells

R.W. Nau
Dept. of Mathematics, Carleton College, Northfield, MN., Intl. J. Earthquake Engr. Struc. Dynam., 4, pp 553-559 (1976)

Key Words: Cylindrical shells, Natural frequencies

Methods for obtaining bounds on natural frequencies are demonstrated for the free vibration of thin, clamped cylindrical shells. The upper bounds are obtained by a Rayleigh-Ritz procedure. The lower bound method used is an extension of one previously applied to simpler structures; the extension is needed to adjust to limit points in a spectrum. For both bounds the problems reduce to matrix eigenvalue problems. Numerical techniques are employed to keep the order of these reduced problems small.

77-535

Response of Shells to Acoustic Shocks

J.M. Klosner
Dept. of Aerospace Engrg. and Applied Mechanics, Polytechnic Inst. of New York, Brooklyn, NY., Rept. No. POLY-AE/AM-76-9, 14 pp (May 1976)
AD-A028 983/5GA

Key Words: Shells, Interaction: fluid-structure, Fluid-induced excitation, Acoustic excitation

The past 25 years have witnessed a multitude of studies relating to fluid-structure interaction. Such a wide range of problems have been investigated that an attempt to review all of the relevant literature, within the confines of one paper, would, of necessity, be sketchy. Accordingly, this review is limited to investigations concerned with the response to acoustic shocks of shells submerged in a fluid of infinite expanse. Even in this restricted domain, there is an extensive literature. Those references most pertinent to the subject matter have been included; numerous investigations in the Russian literature have not been. However excellent detailed reviews and discussions of Russian literature have been published.

77-536

Spectrum and RMS Levels for Stresses in Closely Spaced Stiffened Cylindrical Shells, Subjected to Acoustic Excitation

G. Maymon
Armament Development Authority, Haifa, Israel, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 25-35 (1976) 10 figs, 10 refs

Key Words: Cylindrical shells, Stiffened shells, Acoustic excitation, Donnel theory

A formulation, by which RMS values of stresses in cylindrical shells with closely spaced stiffeners subjected to acoustic excitation can be obtained, is presented. A digital computer program, based on the present formulation was written, and numerous examples for unstiffened shells are presented. Noise reduction information is obtained.

77-537

On the Dynamic Response and Failure of Stiffened and Unstiffened Cylindrical Shells Under Axial Impact

G. Maymon and A. Libai
Dept. of Aeronautical Engineering, Technion - Israel Inst. of Tech., Haifa, Israel, Rept. No. TAE-275, 45 pp (Mar 1976)
N76-29647

Key Words: Cylindrical shells, Axial excitation, Computer programs

Time history of the expected values of stresses and radial displacements in imperfect, closely spaced, stiffened cylindrical shells subjected to axial impact is analyzed. A specially constructed computer program is utilized for presenting several numerical parametric studies of axially stiffened shells. Of interest is the apparent existence of an optimal size of stiffening.

77-538

Dynamic Response of Laminated Composite Shells

C.T. Sun
Dept. of Engrg. Science and Mechanics and Engrg. Research Inst., Iowa State Univ., Ames, IA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 17-22 (1976) 6 figs, 8 refs

Key Words: Composite structures, Shells, Pulse excitation

In this paper the classical method of separation of variables, combined with the Mindlin-Goodman procedure, is employed to analyze the dynamic response of a simply-supported composite shell under a uniform dynamic pressure on the inner surface of the shell.

77-539
Fundamental Frequency of Vibration of Clamped Plates of Arbitrary Shape Subjected to a Hydrostatic State of In-Plane Stress
P.A.A. Laura and R. Gutierrez
Inst. of Applied Mechanics, Base Naval Puerto Belgrano, Argentina, J. Sound Vib., 48 (3), pp 327-332 (Oct 8, 1976) 2 figs, 12 refs

Key Words: Plates, Natural frequencies, Conformal mapping, Galerkin method

The present paper makes use of conformal mapping and Galerkin's method to determine the fundamental frequency of vibration of clamped plates of arbitrary shape subjected to uniform in-plane stress. Numerical results are presented for several plates of regular polygonal shape. Frequency curves obtained by means of Lurie's expression are also given for simply supported plates.

77-540
A Reduction Method for Problems of Vibration of Orthotropic Plates
T. Sakata
Dept. of Mech. Engrg., Chubu Inst. of Technology, Kasugai, Nagoya-sub., Japan 487, J. Sound Vib., 48 (3), pp 405-412 (Oct 8, 1976) 2 figs, 13 refs

Key Words: Plates, Orthotropism, Natural frequencies

It is shown that the problem of vibration of an orthotropic plate can be reduced to that of another orthotropic plate by a simple co-ordinate transformation, and reduction formulae are obtained. As an example, an exact natural frequency of a simply supported generally orthotropic skew plate with special flexural rigidities is obtained from that of a simply supported isotropic rectangular plate.

77-541
Increasing the Natural Frequency and the Buckling Load by Suitable Plastic Deformation
F.G. Rammerstorfer and R. Beer
Inst. fuer Allgemeine Mechanik, T.U. Wien, Austria, Forsch. Ingenieurw, 42 (5), pp 168-172 (1976) 9 figs, 6 refs
(In German)

Key Words: Plates, Natural frequency, Plastic deformation

A possibility of the improvement of the dynamical behavior and the stability of structures without using an additional consumption of material or better but more expensive materials is shown by the influence of self stresses. As an example prestressed circular plates are discussed, its natural frequency and its buckling load are increased by suitable states of self stresses. The results of an optimization of fields of self stresses are presented and an experiment shows a practicability of producing useful self stresses.

SYSTEMS

ABSORBER

(Also see No. 578)

77-542
Polyurethane Integral Foams for Safety In or On Motor Vehicles
H. Schafer
Leverkusen, Germany, Automobil-tech. Z., 78 (9), pp 361-365 (Sept 1976) 9 figs
(In German)

Key Words: Collision research (automotive), Foams, Energy absorption

Characteristics of a new material which provides increased safety, avoids minor types of damage on motor vehicles, and offers an extended range in the forms of application to car constructors and designers are presented.

ACOUSTIC ISOLATION

77-543

Noise Barrier Screen Measurements: Single Barriers

R.N. Foss

Applied Physics Lab., Washington Univ., St. Louis, MO., Rept. No. PB-250971/9; APL-UW-7509; Rept 24.1, 71 pp (June 1975)

Sponsored by DOT

N76-28963

Key Words: Noise barriers, Experimental data, Noise measurement

Measurements on screen noise barriers are reported. The results of calculations that convert point source curve to the incoherent line source (and line source segment) case are also given. The measurements were conducted at two frequencies and employed a variety of source-to-wall and wall-to-microphone spacings. They were carried out indoors using pulse techniques to eliminate unwanted bounces and reflections.

NOISE REDUCTION

(Also see No. 573)

77-544

Noise Suppression with High Mach Number Inlets

E. Lumsdaine, J.G. Cherng and I. Tag

Tennessee Univ., Knoxville, TN., Rept. No. NASA-CR-2708, 108 pp (July 1976)

N76-28959

Key Words: Noise reduction

Experimental results were obtained for two types of high Mach number inlets, one with a translating centerbody and a fixed geometry inlet (collapsing cowl) with no centerbody. The aerodynamic and acoustic performance of these inlets were examined. The effects of area ratio, length/diameter ratio, and lip geometry were among several parameters investigated. The translating centerbody type inlet was found to be superior to the collapsing cowl both acoustically and aerodynamically, particularly for area ratios greater than 1.5. Comparison of length/diameter ratio and area ratio effects on performance near choked flow showed the latter to be more significant.

77-545

Concrete Walls for Highway Noise Reduction

E.C. Lokken

Portland Cement Assoc., Skokie, IL., ASCE Transp. Engr. J., 102 (TE4), pp 637-649 (Nov 1976)

Key Words: Noise barriers, Walls, Concrete construction, Traffic noise

Sound walls are being used to reduce the impact of traffic noise on residential and business installations adjacent to major urban traffic routes. Noise wall projects using cast-in-place concrete, precast concrete panels, concrete masonry units, and plaster or air-placed concrete are described.

77-546

Techniques for Noise Exposure Control in Existing Power Plants

R.A. Popeck

Engrg. Research Dept., The Detroit Edison Co., Detroit, MI., J. Engr. Power, Trans. ASME, 98 (4), pp 487-492 (Oct 1976) 13 figs

Paper No. 75-WA/Pwr-6

Key Words: Electric power plants, Noise reduction, Industrial facilities

The control of noise exposure in existing power plants is discussed. Among the difficulties encountered in a noise control program are identification of sources of high sound levels; identification of personnel exposure; and identification of feasible means to control sound levels. This paper describes procedures and equipment which can be used to control noise exposure in existing power plants.

AIRCRAFT

(Also see No. 565)

77-547

V/STOL Aircraft Noise Prediction (Jet Propulsors)

N.N. Reddy, D.F. Blakney, J.G. Tibbets and J.S. Gibson

Lockheed-Georgia Co., Marietta, OH., Rept. No. LG75ER0054, FAA-RD-75-125, 327 pp (June 1975)

AD-A028 765/6GA

Key Words: Aircraft noise, Computer programs, Noise prediction

A computer program is presented for predicting the noise levels of V/STOL aircraft with jet-propulsive-lift systems. Using the equations developed in Part I of this report the noise levels may also be estimated with hand calculations. Vectored thrust, externally blown flap, upper surface blown flap, internally blown flap, and augmentor wing are the propulsive-lift concepts considered. Semi-empirical equations are derived using the test results and theories for the following aricraft noise sources: Internal engine, jet, excess (core engine), high-lift system, airframe, and auxiliary power unit. A computer program predicts the perceived noise levels and tone corrected perceived noise levels for V/STOL aircraft at any specified sideline distance for known geometrical and operational parameters.

77-548

Landing Gear and Cavity Noise Prediction

D.B. Bliss and R.E. Hayden

Bolt Beranek and Newman, Inc., Cambridge, MA., Rept. No. NASA-CR-2714, 57 pp (July 1976)

N76-28961

Key Words: Aircraft noise, Landing gear, Noise prediction

Prediction of airframe noise radiation from the landing gear and wheel wells of commercial aircraft is examined. Measurements of these components on typical aircraft are presented. Potential noise sources are identified. Semiempirical expressions for the sound generation by these sources are developed from available experimental data and theoretical analyses. These expressions are employed to estimate the noise radiation from the landing gear and wheel wells for a typical aircraft and to rank order the component sources.

77-549

Effects of Motion on Jet Exhaust Noise From Aircraft. Final Report

K.S. Chun, C.H. Berman and S.J. Cowan

Boeing Commercial Airplane Co., Seattle, WA., Rept. No. NASA-CR-2701; D6-41995, 221 pp (June 1976)

N76-28960

Key Words: Aircraft noise, Jet noise

The various problems involved in the evaluation of the jet noise field prevailing between an observer on the ground and an aircraft in flight in a typical takeoff or landing approach pattern were studied. Areas examined include literature survey and preliminary investigation, propagation effects, source alteration effects, and investigation of verification techniques. Sixteen problem areas were identified and studied.

77-550

Airframe Self-Noise: Four Years of Research

J.C. Hardin

NASA, Langley Research Center, Langley Station, VA., Rept. No. NASA-TM-X-73908, 73 pp (July 1976)

N76-28957

Key Words: Aircraft noise, Self-excited vibrations, Reviews

A critical assessment of the state of the art in airframe self-noise is presented. Full-scale data on the intensity, spectra and directivity of this noise source are evaluated. Vibration of panels on commercial aircraft is identified as a possible additional source of airframe noise. The present understanding and methods for prediction of other component sources - airfoils, struts, and cavities - are discussed. The various experimental methods which have been developed for airframe noise research are discussed and sample results are presented.

77-551

Structural Identification on the Ground and in Flight Including Command and Stability Augmentation System Interaction

AGARD, Paris, France, Rept. No. AGARD-R-646, 61 pp (1976)

AD-A028 982/7GA

Key Words: Aircraft, Mathematical models, Stability analysis, Finite element technique

The four papers which comprise this report are all concerned in some way with the comparison between the mathematical model of the ariplane and its actual behavior on the ground or in flight. New structural testing methods are presented, which make it possible to provide the designer with accurate results for comparison with the finite element description of the structure, and with corrections to this model. A summary is given of the work done on the MRCA, from the design stage to the flight flutter test, to understand and analyze the aeroelastic phenomena. New reduction techniques which greatly improve the accuracy of flight flutter test results are presented. The final paper shows how the problem of interactions between the aircraft structure and the command and stability augmentation system has been solved on the MRCA.

77-552

Coherence Methods Used to Define Transmission Paths in Airborne Antenna Vibration

J. Pearson and R.E. Thaller

Air Force Flight Dynamics Lab., Wright-Patterson AFB, OH 45433, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 49-56 (1976) 3 figs, 11 refs

Key Words: Antennas, Aircraft equipment, Vibration isolation, Vibration control

Conditional coherence functions are used in a practical mechanical vibration problem to determine which of several possible inputs are the major causes of vibration of an airborne antenna. Pairwise, multiple, and multiple conditional coherence spectra are derived from flight vibration data. The vibratory inputs causing several important antenna responses are identified despite correlations between inputs.

77-553

Mathematical Approaches to the Dynamics of Deformable Aircraft

Royal Aircraft Establishment, Farnborough, England, Rept. No. ARC-R/M-3776-Mono; RAE-TM-Struct-807; RAE-TR-71131; RAE-TR-71227, 125 pp (1976) N76-28195

Key Words: Aircraft, Flutter

Descriptions of two separate mathematical approaches to the dynamical problems of deformable aircraft are presented. The preface discusses the long-standing need for a philosophy to unify the work of stability and control specialists on the one hand and of flutter and gust response specialists on the other. Attempts to extend to deformable aircraft the concepts developed for the rigid aircraft in classical stability and control theory are made.

77-554

Geared-Elevator Flutter Study

C.L. Ruhlin, R.V. Doggett, Jr. and R.A. Gregory

Boeing Commercial Airplane Co., Seattle, WA., Rept. No. NASA-TM-X-73902, 12 pp (May 1976) N76-28158

Key Words: Flutter, Airframes

An experimental and analytical study was made of the transonic flutter characteristics of a supersonic transport tail assembly model having an all-movable, horizontal tail with a geared elevator. Flutter calculations (mathematical models) were made for the geared-elevator configuration using three subsonic lifting-surface methods. In one method, the elevator was treated as a discrete surface, and in the other two methods, the stabilizer and elevator were treated as a single warped-surface with the primary difference between these two methods being in the mathematical implementation used. A comparison of the experimental and analytical results shows that the discrete-elevator method predicted best the experimental flutter dynamic pressure level. However, the single warped-surface methods predicts more closely the experimental flutter frequencies and Mach number trends.

77-555

Drag Effects on Wing Flutter

A. Petre and H. Ashley

Polytechnic Institute, Bucharest, Romania, J. Aircraft, 13 (10), pp 755-763 (Oct 1976) 5 figs, 7 refs

Key Words: Aircraft wings, Flutter, Fluid-induced excitation

Using the large-aspect-ratio, cantilever wing as a model, the question is addressed as to whether forces of a drag type may have a significant influence on dynamic aeroelastic stability. The elementary example of an elastically suspended "typical section" airfoil with constant drag and quasisteady airloads is analyzed.

77-556

Digital Time Series Analysis of Flutter Test Data

R.W. Lenz and D.A. Foreman

Air Force Flight Test Center, Edwards AFB, CA., In: AGARD Structural Identification on the Ground and in Flight Including Command and Stability Augmentation System Interaction June 1976, pp 7-24 (N76-29656)
N76-29658

Key Words: Aircraft, Flutter, Digital simulation

A minicomputer based digital time series analysis system is used at the Air Force Flight Test Center to provide near real time estimates of modal parameters during flight flutter testing.

77-557

Structural Identification on the Ground and in Flight Including Command and Stability Augmentation System Interaction

AGARD, Paris, France, Rept. No. AGARD-R-646, 57 pp (June 1976)
N76-29656

Key Words: Aircraft, Spacecraft, Vibration tests, Flutter

Papers are presented which deal with vibration testing of aircraft and rocket vehicles, flutter analysis, particularly of the MRCA aircraft, digital techniques for flutter analysis, and interactions between aircraft structures and the command and stability augmentation system of the MRCA.

77-558

An Assessment of the Importance of the Residual Flexibility of Neglected Modes in the Dynamical Analysis of Deformable Aircraft

A.S. Taylor and M.R. Collyer

Structures Dept., Royal Aircraft Establishment, Farnborough, England, Rept. No. ARC-CP-1336; RAE-TR-73119; ARC-35085, 78 pp (1976)

N76-30171

Key Words: Aircraft, Modal analysis

The mathematical framework for a unified approach to the dynamical problems of deformable aircraft is used as the basis for a limited numerical investigation of the usefulness of the residual flexibility concept in truncated modal analyses. A finite element model of a supersonic transport aircraft of slender delta configuration is the subject of stability and response calculations.

77-559

The Longitudinal Equations of Motion of a Tilt Prop/Rotor Aircraft Including the Effects of Wing and Prop/Rotor Blade Flexibility

H.C. Curtiss, Jr.

Dept. of Aerospace and Mech. Sciences, Princeton Univ., NJ., Rept. No. NASA-CR-137855; TR-1273, 63 pp (Apr 1976)

N76-28226

Key Words: Aircraft, Equations of motion, Dynamic analysis

The equations of motion for the longitudinal dynamics of a tilting prop/rotor aircraft are developed. The results of body freedom can be added to the equations of motion for the flexible wing propeller combination.

77-560

The Dynamics of Deformable Aircraft

D.L. Woodcock

Royal Aircraft Establishment, Farnborough, England, In: its Math. Approaches to the Dyn. of Deformable Aircraft 1976, pp 77-123 (N76-28195 19-02)

N76-28197

Key Words: Aircraft, Dynamic analyses, Equations of motion

The choice of a way of formulating the equations of motion of a deformable aircraft is considered. Emphasis is placed on ease of understanding and application.

77-561

Boundary Layer Fluctuating Pressure Data Obtained in a High Background Noise Environment on a Small Scale Wind Tunnel Model

G.L. Getline

General Dynamics Convair Div., San Diego, CA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 1-9 (1976) 7 figs, 4 refs

Key Words: Aircraft, Aerodynamic response, Wind tunnel tests

Because flow visualization studies on a small wind tunnel model of a new Navy fighter design indicated the possibility of aerodynamic flow separation over the cockpit canopy in the transonic flight regime and under some maneuvering conditions, it was decided to instrument an available small scale model in order to obtain boundary layer fluctuating pressure data in the transonic and supersonic flight regimes. These data could then be used to provide estimates of cockpit interior noise levels for the full scale aircraft during high speed flight.

77-562

New Structural Testing Methods Based on Non-Appropriated Excitation

G. Piazzoli

Office National d'Etudes et de Recherches Aerospatiales, Paris, France, In: AGARD Structural Identification on the Ground and in Flight Including Command and Stability Augmentation System Interaction June 1976, pp 1-6 (N76-29656)

(In French)

N76-29657

Key Words: Aircraft, Spacecraft, Wing stores, Testing techniques, Computer programs

After recalling the classical methods for determining the vibratory characteristics of an aircraft or rocket structure by a test with appropriated excitation, the paper presents two new methods that do not deliver appropriation.

BRIDGES

77-563

Earth ake-Indu ed Dynamic Response of Bridges and Br ge Measurements

R.B. Matthiesen

Transportation Research Board, Washington, D.C., Rept. No. TRB/TRR-579, ISBN-0-309-02493-5, 108 pp (1976)

PB-256 523/2GA

Key Words: Bridges, Seismic response, Earthquakes

The papers in this proceedings deal with a description of the strong-motion instrumentation program for state highway bridges; a description of retrofit measures to improve the seismic performance of existing highway bridges and a discussion of a numerical seismic method of analyzing their effectiveness; a discussion of research on a model relating to the seismic resistance of large multispan curved overcrossings; a description of new seismic design criteria for bridges that consider both fault proximity and local soil conditions; a description of applications of bridge measurement data to fatigue design including impact, girder load distribution, fatigue life stress cycles, predicted and measured stresses, and the potential for weighing trucks in motion on bridges; a description of field testing of the Aguasabon River bridge in Ontario; a discussion of an analytical method for determining the response of horizontally curved bridges to loads; a presentation of a seven-step procedure for using stress history data to predict stress in bridge girders; and a presentation of a rational approach for determining remaining fatigue life of a bridge.

BUILDING

77-564

Concorde Noise-Induced Building Vibrations, Montgomery County, Maryland

W.H. Mayes, H.F. Scholl, D.G. Stephens, B.G. Holliday, R. DeLoach, T.D. Finley, H.K. Holmes, R.B. Lewis and J.W. Lynch

NASA, Langley Research Center, Langley Station, VA., Rept. No. NASA-TM-X-73947; Rept-3, 43 pp (Aug 1976)

N76-30923

Key Words: Buildings, Vibration response, Aircraft noise

A series of studies are reported to assess the noise induced building vibrations associated with Concorde operations. The levels of induced vibration and associated indoor/outdoor noise levels resulting from aircraft and nonaircraft events in selected homes, historic and other buildings near Dulles International Airport were recorded.

77-565

Concorde Noise-Induced Building Vibrations, Sully Plantation - Report No. 2, Chantilly, Virginia

NASA, Langley Research Center, Langley Station, VA., Rept. No. NASA-TM-X-73926; Rept-2630, 46 pp (June 1976)

N76-30603

Key Words: Buildings, Vibration response, Aircraft noise

Noise-induced building vibrations associated with Concorde operations were studied. The approach is to record the levels of induced vibrations and associated indoor/outdoor noise levels in selected homes, historic and other buildings near Dulles International Airport.

HELICOPTERS

(Also see No. 480)

77-566

Evaluation of the Environmental Impact and Recommended Control Measures to Reduce the Noise Generated from Military Helicopter Operations at the McGuire Veterans Administration Hospital, Richmond, Virginia

M.W. Mueller

Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD., Rept. No. USAEHA-34-018-75, 41 pp (Oct 1974)

AD-B004 485/9GA

Key Words: Helicopter noise, Noise tolerance

An evaluation was made to determine the extent to which noise from helicopter operations at the McGuire Veterans Administration Hospital helipad could affect nearby residential areas and the hospital activities. No adverse impact was found and little or no annoyance is anticipated. Recommendations were made to further minimize the chance of annoyance.

77-567

An Introduction to Helicopter Air Resonance

A.R.S. Bramwell

City Univ., London, England, Rept. No. ARC-R/M-3777; ARC-33886, 31 pp (1975)

N76-30226

Key Words: Helicopters, Resonance

The phenomenon known as air resonance, peculiar to helicopters with hingeless rotors, is analyzed and presented.

77-568

Vibration Measurements on the Rotor Shaft of the UH-1M Helicopter

H.I. Goldman

Frankford Arsenal, Philadelphia, PA., Rept. No. FA-TR-76009, 18 pp (Feb 1976)

AD-A028 924/9GA

Key Words: Helicopters, Vibration measurement

This report describes a program of in-flight vibration measurements carried out on a platform mounted atop the rotor mast on the UH-1M helicopter. Results of a real time analysis of the data are presented.

77-569

The Evaluation of Human Exposure to Helicopter Vibration

M.J. Griffin

Inst. of Sound and Vibration Res., Southampton Univ., Southampton, England, Rept. No. ISVR-TR-78, 46 pp (Sept 1975)

N76-30816

Key Words: Helicopter vibration effects, Human response

The form of a new procedure for evaluating helicopter vibration is described. Guidance to aircraft designers is offered for three categories of vibration exposure: whole-body vibration of aircrew, the legibility of vibrating instruments, and local vibration of aircrew heads, hands, and feet. The derivation of the evaluation procedure is presented and areas where more research is required are defined. Examples of how the procedure may be used to evaluate helicopter vibration are given and the vibration conditions reported in some helicopters are compared with the recommended vibration limits.

HUMAN

(Also see No. 569)

77-570

Duration of Whole-Body Vibration Exposure: Its Effect on Comfort

M.J. Griffin and E.M. Whitham

Inst. of Sound and Vibration Res., Univ. of Southampton, Southampton S09 5NH, England, J. Sound Vib., 48 (3), pp 333-339 (Oct 8, 1976) 3 figs, 13 refs

Key Words: Vibration excitation, Human response

The experiment described in this paper was conducted to determine whether the relative discomfort produced by 4 Hz and 16 Hz sinusoidal whole-body vertical vibration was dependent on the duration of the vibration exposure.

ISOLATION

(Also see Nos. 529, 530, 552)

77-571

Optimum Linear Preview Control with Application to Vehicle Suspension -- Revisited

M. Tomizuka

Dept. of Mech. Engrg., Univ. of California, Berkeley, CA., J. Dyn. Syst., Meas. and Control, Trans. ASME, 98 (3), pp 309-315 (Sept 1976) 4 figs, 12 refs

Paper No. 76-Aut-PP

Key Words: Suspension systems (vehicles), Optimum control theory

77-632

This paper presents the analysis, design and experimental

Preview control of vehicle suspension as proposed by Bender is studied from the viewpoint of discrete optimal control. Improvements of the suspension system similar to those observed by Bender (reduction of acceleration and suspension clearance space) are rediscovered. The structure of the preview controller derived in this paper is clear, and is suited for practical use.

77-572

Component Testing of Liquid Shock Isolators and Elastomers in Support of Recent Shock Isolation System Designs

J.P. Ashley
Boeing Aerospace Co., Seattle, WA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 205-236 (1976) 39 figs, 8 refs

Key Words: Shock isolation, Foams, Elastomers, Cables, Liquids

Conisderable component testing has been completed to support the design of new shock isolation systems. Early concept development transmissibility testing provided response characteristics for the most suitable candidate shock isolation systems. Tested elements included elastomeric foam, rubber pads, cables, liquid isolators and candidate floor structures. From these test results, optimum characteristics for shock isolation systems were established and subsequently applied toward specific design requirements and weapon system design specifications. Within required design constraints, prototype hardware was fabricated and subsequently subjected to development testing to provide design and analysis data in support of the system shock isolation designs. Computer analysis models were developed to calculate selected responses associated with these new shock isolation systems. This paper is devoted to describing the component dynamic development test and analysis efforts and resulting conclusions which ultimately led to the detail shock isolation system designs which are currently being deployed.

77-573

Evaluation of Isolation Mounts in Reducing Structureborne Noise

T.F. Derby
Barry Div., Barry Wright Corp., Watertown, MA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 163-187 (1976) 43 figs, 7 refs

Key Words: Equipment mounts, Isolators, Noise reduction, Interaction: structure-foundation, Mathematical models, Computer programs

This paper presents an evaluation of the effectiveness of isolators in reducing structureborne noise transmitted from a piece of equipment, through the isolators, to the foundation. The results are based on a theoretical model of equipment, isolator, and foundation represented as internally damped rods. This model is used to represent equipment and foundation structural resonances as well as standing wave effects in the isolator. A computer program is presented that obtains the results in graphical form. Conclusions are drawn, based on the graphical results, as to which quantities should be measured in order to evaluate the effectiveness of isolators and also in regard to the effects of isolator parameters in reducing structureborne noise. The applicability of the analysis to elastomeric and metallic type isolators is also discussed.

77-574

Polyurethane Foam Isolators for Shock Isolated Equipment Floors

W.C. Gustafson
Boeing Aerospace Co., Seattle, WA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 189-204 (1976) 15 figs, 6 refs

Key Words: Shock isolation, Polyurethane resins, Foams, Floors, Nuclear explosions effects, Equipment response

This article presents the results of a large analytical and experimental program that was undertaken in the design and verification of a polyurethane foam isolator set for shock-isolated equipment floors. The operating environment which controlled the system design was ground motion induced by nuclear weapons; the major design constraints were the available space in an existing facility for dynamic floor excursion, and the level of shock attenaution that had to be achieved to ensure equipment survival.

77-575

Analysis and Testing of Full Scale Shock Isolated Equipment Floors

W.R. Milne
Boeing Aerospace Co., Seattle, WA., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 237-252 (1976) 19 figs, 6 refs

Key Words: Shock isolation, Floors, Nuclear explosion effects, Equipment response

Increased nuclear threats have resulted in the need to design an improved equipment floor to ensure survival of electronic equipment critical to a silo-based ICBM system. The design problem had two constaints: to fit the new equipment floor into the existing facility, and to limit the floor response loads and environment to current equipment capabilities. The design criteria associated with the increased facility motion represented a composite shock requirement including motions induced by the airblast and ground-transmitted effects induced by cratering. A simplified analytical model for an equipment floor with idealized vertical and horizontal isolators was established to support selection of a candidate concept that would accommodate both air-induced and cratering response conditions. Component analyses of the liquid isolator and the horizontal foam restraints were developed separately and systematically improved by a series of component test programs.

77-576

The Use of General Purpose Computer Programs to Derive Equations of Motion for Optimal Isolation Studies

W.D. Pilkey, Y.H. Chen and A.J. Kalinowski
Dept. of Engrg. Science and Systems, Univ. of Virginia, Charlottesville, VA 22901, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 269-276 (1976) 5 figs, 5 refs

Key Words: Computer programs, Equations of motion, Optimization, Isolation

Techniques are developed which permit general purpose structural analysis computer programs to be used to generate the equations of motion necessary for limiting performance studies. The limiting performance characteristics of a system are useful in analyzing the optimal behavior of a dynamic system. In particular, the limiting performance characteristics are the essential ingredients in an efficient optimal design method for isolation systems.

METAL WORKING AND FORMING

77-577

Machine Tool Noise Measurements

P.B. Ostergaard
S/V Sound Vib., 10 (10), pp 22-24 (Oct 1976) 2 figs

Key Words: Machine tools, Machinery noise, Noise measurement, Measurement techniques

The National Machine Tool Builders Association (NMTBA) has published the second edition of NMTBA Noise Measurement Techniques. The second edition is an improvement over the first edition (issued in 1970) and now describes procedures for measurement of machine tool noise where it is non-steady. The discussion given in the article is the educational Appendix B of the document, which explains the difference between three decibel and five decibel "equivalent" sound level. It also proposes a designation for the five decibel trade-off equivalent level to avoid confusion with the three decibel trade-off since a lack of clarity on which "equivalent" is used can cause difficulty in evaluating noise exposure of employees.

PACKAGE

77-578

The Development of a Generalized Impact Response Model for a Bulk Cushioning Material

D. McDaniel and R.M. Wyskida
Advanced Systems Concept Office, Res., Dev., Engrg. and Missile Systems Lab., U.S. Army Missile Command, Redstone Arsenal, AL 35809, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 131-142 (1976) 5 figs, 11 refs

Key Words: Packaging material, Test models

This paper presents an automated approach to the design of bulk cushioning systems. The developed procedure can be utilized in package and shipping container design, and other impact absorption applications. A model of impact response is developed and its validity demonstrated through statistical testing. The model is then used as the objective program for a sequential search procedure that searches out the best cushion design.

77-579

Particulate Silicone Rubber: An Effective, Removable Encapsulant for Electronic Packaging

R.R. Palmisano and D.W. Neily
Harry Diamond Laboratories, Adelphi, MD., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 277-284 (1976) 6 figs

Key Words: Packaging, Electronic equipment, Elastomers, Silicone resins

A method of encapsulating electronic circuit board assemblies that enables rapid application and removal of the encapsulant was developed and evaluated. Low-density, inexpensive, foamed silicone rubber particles that are environmentally and electrically stable were used in lieu of conventional hard "potting." The silicone rubber particles can be easily applied by pouring and packing into electronic package voids; they are likewise easily removed from the package (and reusable), should circuit maintenance or rework be necessary. Vibration tests of typical missile-borne applications indicate that, at resonance, electronic circuit board assemblies protected by this method experienced less than 10 percent of the acceleration measured before encapsulation.

77-580

Advances in Shipping Damage Prevention

H. Caruso and W. Silver, II

Produce Qualification Lab., Westinghouse Electric Corp., Baltimore, MD., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 41-48 (1976) 7 figs

Key Words: Transportation effects, Packaging

For several years, Westinghouse Electric Corporation has been studying the transportation of loose cargo in tractor-trailers to determine how products are damaged in shipment and how they can be better designed to resist this damage. During the road test phase of these studies, the following factors were investigated: suspension system types, degree of load, rear wheel position, road types, and different drivers.

PUMPS, TURBINES, FANS, COMPRESSORS

(Also see No. 522)

77-581

An Experimental Investigation on Noise Production and Noise Propagation in Centrifugal Fans

M. Bartenwerfer, R. Agnon and T. Gikadi

Inst. fuer Turbulenzforschung, Deutsche Forschungs- und Versuchsanstalt fuer Luft- und Raumfahrt, Berlin, West Germany, Rept. No. DLR-FB-76-14, 57 pp (Feb 10, 1976)

(In German)

N76-30925

Key Words: Fans, Noise generation, Noise propagation

The harmonic part of the noise of a model fan as well as the random component were measured at three different locations (inlet duct, outlet duct, and at the cutoff) for a tip speed range between 15 to 60 m/s and for a few representative points of the pressure-head volume-flow characteristic.

77-582

Evaluation of Proposed ASME Performance Test Code 36 for Sound Power Level Determination of Large Steam Turbine-Generators

S.E. Grabkowski, J. MacDonald and T.E. VanSchaick

General Electric Corporate Res. and Dev., Schenectady, NY., J. Engr. Power, Trans. ASME, 98 (4), pp 493-500 (Oct 1976) 11 figs, 6 refs

Paper No. 75-WA/PTC-2

Key Words: Steam turbines, Sound level meters, Standards and codes

The "two-surface" correction technique, as it is outlined in ASME Performance Test Code No. 36, is utilized in the determination of large steam turbine-generator sound power level (PWL). Test data obtained from using this method and other PWL calculation methods are presented.

77-583

A Nonlinear Dynamic Model of a Once-Through Subcritical Steam Generator

A. Ray and H.F. Bowman

Stone & Webster Engineering Corp., Boston, MA., J. Dyn. Syst., Meas. and Control, Trans. ASME, 98 (3), pp 332-339 (Sept 1976) 9 figs, 10 refs

Paper No. 76-Aut-M

Key Words: Steam turbines, Mathematical models, Transient response

A dynamic thermal-hydraulic model of a once-through subcritical steam generator is presented which allows the investigation of power plant system transients.

RAIL

77-584

Automated Wheel-on-the-Ground Detection by Derailment Impact Sensing-Analysis and Full Scale Test Results

W.W. Wassmann and J.H. Armstrong

Naval Surface Weapons Center, White Oak, Silver Spring, MD., U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 121-130 (1976) 17 figs, 1 ref

Key Words: Diagnostic techniques, Railroad cars, Seismic detection

This paper describes the establishment of design criteria for a seismic local derailment detector based on the measured environment. Acceleration measurements were also made during normal, over-the-road operations on both the empty and loaded cars, as well as during loading, unloading and coupling operations. All acceleration measurements were made on the unsprung mass portion of the trucks.

REACTORS

77-585

Seismic and Operational Vibration Problems in Nuclear Power Plants

C.B. Smith

Principal, Applied Nucleonics Co., Santa Monica, CA 90024, Shock Vib. Dig., 8 (11), pp 3-11 (Nov 1976) 2 figs, 27 refs

Key Words: Seismic response, Nuclear power plants, Equipment response, Vibration response

This paper presents a brief overview of the following topics: current methods for seismic analysis and design, review of structural and equipment vibration test data, perspective on operational vibration problems, promising new developments, and future research areas.

77-586

Dynamic Loading of Containment During Blowdown: Review of Experimental Data from Marviken and Brunsbuttel

J. Kadlec and R.A. Muller

Institut fuer Reaktorentwicklung, Kernforschungszentrum Karlsruhe, D-7500 Karlsruhe, Germany, Nucl. Engr. Des., 38 (1), pp 143-158 (July 1976) 11 figs, 3 refs

Key Words: Nuclear reactor containment, Dynamic response

This paper deals with the problem of the dynamic loading of the pressure suppression type containment due to pressure fluctuations which are induced during blowdown as a result of steam condensation in the suppression pool. It reviews the experimental data on pressure fluctuations and on the corresponding dynamic response of the structures submerged in the water charge. Two series of containment response experiments were performed on real pressure suppression systems.

77-587

A Fluid-Structure Finite Element Method for the Analysis of Reactor Safety Problems

T.B. Belytschko and J.M. Kennedy

Dept. of Materials Engrg., Univ. of Illinois at Chicago, Chicago, IL 60680, Nucl. Engr. Des., 38 (1), pp 71-81 (July 1976) 8 figs, 14 refs

Key Words: Nuclear reactor containment, Computer programs, Finite element technique

A method is presented for the safety analysis of reactor containment structures by means of finite elements. The finite element equations of both fluid and structural elements for arbitrarily large, non-linear response are developed and the way in which they are combined is indicated. Both explicit and implicit integration of the equations in time is considered. Three examples of the application of these methods to the analyses of reactor safety problems are described.

77-588

LMFBR Subassembly Response to Simulated Local Pressure Loadings

T.J. Marciniak, A.H. Marchertas and D.J. Cagliostro

Reactor Analysis and Safety Div., Argonne National Lab., Argonne, IL 60439, Nucl. Engr. Des., 38 (1), pp 1-14 (July 1976) 21 figs, 10 refs

Key Words: Nuclear reactor components, Ducts, Dynamic response, Finite element technique, Nuclear reactor containment

The structural response of liquid metal fast breeder reactor (LMFBR) subassemblies to local accidental events is of interest in assessing the safety of such systems. Problems to be resolved include failure propagation modes from pin to pin and from subassembly to subassembly. Factors considered include the geometry of the structure, uncertainty of the pressure - energy source, uncertainty of materials properties under reactor operating conditions, and the difficulty in performing in-pile or out-of-pile experiments which would simulate the above conditions. The main effort in evaluating the subassembly response has been centered around the development of appropriate analyses based on the finite element technique. Analysis has been extended to include not only the subassembly duct structure itself, but also the fluid environment, both within subassemblies and between them. These models and codes have been devised to cover a wide range of accident loading conditions, and can treat various materials as their properties become known. The effort described here is centered mainly around an experimental effort aimed at verifying, modifying or extending the models used in treating subassembly damage propagation.

77-589

On the Dynamic Response of EBR-II Ducts to Pressure Pulses

P.S. Chopra and S. Srinivas

Argonne National Lab., Argonne, IL 60439, Nucl. Engr. Des., 38 (1), pp 15-27 (July 1976) 19 figs, 8 refs

Key Words: Nuclear reactor components, Ducts, Dynamic response, Dynamic tests, Finite element technique, Computer programs, Nuclear reactor containment

Preliminary dynamic stress analyses of ducts to pressure pulses have been conducted using a one-dimensional finite element code. A comoarison of analytical predictions of maximum permanent duct deflection between flats and test results is presented in this paper.

77-590

Soil-Structure Interaction for Nuclear Power Plants

J.R. Hall, Jr. and J.F. Kissenpfennig

D'Appolonia (E.) Consulting Engineers, Inc., Brussels, Belgium, In: Roy. Neth. Meteorol. Inst. on Earthquake Risk for Nucl. Power Plants, Jan 1976, pp 113-119 (N76-31787)

N76-31803

Key Words: Nuclear power plants, Interaction: soil-structure, Mathematical models, Lumped parameter method

Basic principles of soil-structure interactions are reviewed. Advantages and limitations of lumped parameters and finite element approaches are discussed. An approach for extending the lumped parameter model to include deeply embedded foundations is presented. The state-of-the-art of field and laboratory measurements of dynamic subsoil properties is briefly discussed.

77-591

Structural Response of Fast Breeder Reactors to Hypothetical Core Disruptive Accidents

S.H. Fistedis

Reactor Analysis and Safety Div., Argonne National Lab., Argonne, Il 60439, Nucl. Engr. Des., 38 (1), pp 43-54 (July 1976) 8 figs, 22 refs

Key Words: Nuclear reactor components, Transient response, Nuclear reactor containment, Computer programs

Liquid metal-cooled fast breeder reactors (LMFBRs) so far have been analyzed for the consequences on the plant and the environment for hypothetical core disruptive accidents (HCDAs). To provide the appropriate analytical tools for this effort, analysis and codes are currently under development in several countries. They combine the hydrodynamics and solid mechanics (and more recently the bubble dynamics) phenomena to gage stresses, strains, and deformations of the important components of the system, and the overall adequacy of the primary and secondary containments. The effort is partitioned into the structural analysis of the core components, and the primary system components beyond the core.

77-592

Experimental Verification of Structural Models to Analyze the Nonlinear Dynamics of LMFBR Fuel Elements

R. Liebe

Institut fuer Reaktorentwicklung, Kernforschungszentrum Karlsruhe, D-7500 Karlsruhe, Germany, Nucl. Engr. Des., 38 (1), pp 29-41 (July 1976) 14 figs, 20 refs

Key Words: Nuclear reactor components, Nuclear fuel elements, Test models, Dynamic tests, Nuclear reactor containment

A short description is given of relevant physical effects, for instance the interaction of two distinct deformation modes of the externally-loaded fuel element. The role of the fuel-pin bundle inside the wrapper is briefly mentioned. Special discrete models were developed which are characterized by lumped point masses connected by elastoplastic beams or nonlinear springs. A brief discussion of an experimental program is then given designed to verify theoretical models and underlying hypotheses.

77-593

Seismic Design Spectra for Nuclear Power Plants: State-of-the-Art

A.P. Michalopoulos and D.K. Shukla

D'Appolonia (E.) Consulting Engineers, Inc., Brussels, Belgium, In: Roy. Neth. Meteorol. Inst. on Earthquake Risk for Nucl. Power Plants, Jan 1976, pp 147-155 (N76-31787)

N76-31806

Key Words: Nuclear power plants, Seismic design, Modal analysis

Standard design response spectra are reviewed and illustrated with data relevant to hard or rock sites. Nuclear power plant design involves design response spectra and modal analysis of a mathematical idealization of the actual structure. The design response spectra give the maximum response of single degree of freedom viscously damped oscillators to ground acceleration as a function of time. A set of design response spectra applicable to rock sites is recommended.

77-594

Structural Shock Tests of Prototype FBR "Monju" Scale Models

A. Takei, M. Matsumura, O. Kawaguchi, K. Okabayashi, Y. Ando and S. Kondo

Power and Control Lab., R & D Center, Toshiba, Kawasakiku, Kawasaki, Japan, Nucl. Engr. Des., 38 (1), pp 109-129 (July 1976) 12 figs, 3 refs

Key Words: Nuclear reactors, Shock tests, Model testing

This paper presents some results of experiments which simulate the structural dynamic response of a LMFBR primary coolant boundary to a hypothetical core disruptive accident (HCDA) based on scale models and high explosives.

77-595

Dynamic Transient Behaviour of Two- and Three-Dimensional Structures Including Plasticity, Large Deformation Effects and Fluid Interaction

D. Shantaram, D.R.J. Owen and O.C. Zienkiewicz

Dept. of Civil Engrg., Osmania Univ., Hyderabad, India, Intl. J. Earthquake Engr. Struc. Dynam., 4, pp 561-578 (1976)

Key Words: Interaction: solid-fluid, Nonlinear response, Finite element technique, Nuclear reactors

The finite element method is employed in the prediction of the dynamic transient response of two- and three-dimensional solids exhibiting geometric (large deformations) and material (elasto - plastic) non-linearities. Explicit time marching schemes are adopted for integration of the dynamic equilibrium equation and a diagonal 'lumped' mass matrix is employed with a special procedure applicable to parabolic isoparametric elements. A variety of problems are presented including a solid/fluid interaction situation, and the method is shown to be able to solve economically many problems of dynamic or catastrophic nature which can occur is such structures as nuclear reactors, and containment vessels.

77-596

Design Spectra for Nuclear Power Plants

R.A. Guzman and P.C. Jennings

Long Beach, CA., ASCE J. Power Div., 102 (PO2), pp 165-178 (Nov 1976)

Key Words: Nuclear power plants, Seismic design

A realistic determination of the design level of vibratory ground motion for nuclear power plants can be obtained by direct analysis of response spectra of existing accelerograms recorded under conditions representative of the Safe Shutdown Earthquake (SSE). The accelerograms recorded under conditions representative of the SSE are identified on the basis of the geologic and seismologic characteristics of the SSE.

RECIPROCATING MACHINE

77-597

Effect of Manifold Design and Firing Order on the Short Term Spectrum

K. Bright and D.W. Thomas

Dept. of Electronics, Univ. of Southampton, Southampton SO9 5NH, England, J. Sound Vib., 48 (3), pp 393-403 (Oct 8, 1976) 13 figs, 7 figs

Key Words: Manifolds, Engine noise

Separation by homomorphic filtering of the engine speed dependent harmonics from the remaining components of a vehicle's acoustic emission involves selection of the optimum frequency for filter. Comparisons are made between the engine harmonics displayed from segments of time series containing different numbers of crankshaft rotations. Finally graphs are included where meaningful comparison can be made between homomorphed spectra of two different vehicles of the same type.

77-598

Frequencies and Mode Shapes of Geometrically Axisymmetric Structures: Application to a Jet Engine

P. Trompette and M. Lalanne

Institut National des Sciences Appliquees, Villeurbanne, France, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 117-122 (1976) 3 figs, 14 refs

Key Words: Jet engines, Axisymmetric bodies, Natural frequencies, Mode shapes, Finite element technique, Fourier series

The vibrations of axisymmetric structures are studied using a Fourier series development and the finite element technique. The general differential equation for rotating thin or thick structures is presented. Here the Coriolis effect is neglected and frequencies and mode shapes of the system are obtained using a simultaneous iteration technique. The method is first tested on simple examples and then applied to a part of a jet engine.

ROAD

(Also see Nos. 464, 473, 501, 571)

77-599

A Discrete Mechanical Model of a Tri-Axle Motor Vehicle

A. Nalecz
Polish Academy of Sciences, Warsaw, Poland, 82 pp (Nov 25, 1975)
(In Polish)
N76-28552

Key Words: Motor vehicles, Vibration response, Test models

A mechanical model of a motor vehicle is constructed to analyze vibrations from the point of view of applicability. Problems of automobile stability and controllability are analyzed by means of theoretical calculations.

77-600

Cornering Compliance Applied to Dynamics of Rolling Vehicles

F.J. Winsor
Chrysler Corp., SAE Paper No. 760711, 12 pp, 7 figs, 8 refs

Key Words: Automobiles, Mathematical models, Design techniques

Simplified mathematical models of the automobile are useful for analyzing the design of new vehicles and for studying the dynamics of driver/vehicle systems. For this study, the equations are linearized about straight-line motion, and an orthogonal axis system is employed. Root locus techniques are used to predict the effect of roll steer on transient behavior. Frequencies and decay rates for the transfer function polynomials are approximated by simple expressions involving cornering compliances. The results facilitate physical interpretation and include the influence of roll steer on dynamic behavior.

77-601

The Cornering Compliance Concept for Description of Vehicle Directional Control Properties

R.T. Bundorf and R.L Leffert
General Motors Corp., SAE Paper No. 760713, 16 pp, 8 figs, 7 refs

Key Words: Automobiles, Mathematical models, Design techniques

The automobile directional control system is not easily simplified and the description of its design or engineering properties has necessarily been complex. In this paper, a concept for combining most vehicle design parameters into two terms, front and rear cornering compliance, is proposed. Analysis and simulation results are presented to illustrate the correspondence between the front and rear cornering compliance parameters and vehicle steady state and transient responses.

77-602

The Truck Driveline as a Source of Vibration

R.G. Joyner
Universal Joint Div., Dana Corp., SAE Paper No. 760843, 16 pp, 17 figs, 1 ref

Key Words: Driveshafts, Trucks, Vibration response

The driveline in a truck can be the source of vibrations. This paper explains and gives corrective procedures for driveline vibrations caused by unbalance, torsional excitation, inertia excitation and secondary couple effect. It also briefly explains the influence of the driveline on the system bending resonance of the truck's engine-transmission package.

77-603

Measurement and Analysis of Truck Power Train Vibration

R.L. Fox
IRD Mechanalysis, Inc., Columbus, OH, SAE Paper No. 760844, 24 pp, 18 figs, 3 refs

Key Words: Measurement techniques, Measuring instruments, Trucks, Vibration response

Portable instruments and techniques have been developed and are readily available to permit accurate measurement and analysis of annoying truck driveline vibration. Problems such as unbalance of the engine, clutch, cooling fan or other rotating components; looseness; resonance; misalignment; defective bearings and gears can be readily identified by carefully comparing the vibration amplitude, frequency and phase characterisitcs unique to each problem.

77-604

Finite Mode Bond Graph Representation of Vehicle -- Guideway Interaction Problems

D. Margolis
Dept. of Mech. Engrg., Univ. of California, Davis, CA,
J. Franklin Inst., 302 (1), pp 1-17 (July 1976) 9 figs, 11 refs

Key Words: Interaction: vehicle-guideway, Modal analysis

Classical modal analysis techniques for the prediction of vehicle-guideway dynamics are developed and interpreted with bond graph representations. Bond graphs are shown to allow easy generalization to multiple span guideways incorporating virtually any dynamic boundary conditions at the support locations. In addition, non-linear vehicle models can be used with any vehicle displacement-time history desired. Straightforward formulation procedures are also provided through the bond graph representation. The analysis procedure is demonstrated for a two-span Bernoulli-Euler Guideway with first-order dynamic boundary conditions. The results for a vehicle traveling at different speeds are shown to compare favorably with current literature.

77-605

Influence of Tire Design Parameters on Tire Force and Moment Characteristics

D.J. Schuring, G.A. Tapia, and I. Gusakov
Calspan Corp., SAE Paper No. 760732, 20 pp, 32 figs, 4 refs

Key Words: Tire characteristics, Computer programs

A comprehensive cornering and braking tire test program performed on 380 tires under uniform and strickly controlled conditions resulted in 13 performance characteristics measured at 4 to 6 different loads for each tire. All performance characteristics (more than 25,000) together with tire design and construction information were organized in a computer program that would quickly extract, correlate, and display any data of interest. As examples of the capabilities of the program, the gross effects of wheel diameter, aspect ratio, cord and belt material, and tire construction on linear and non-linear tire cornering and braking characteristics are identified.

ROTORS

(Also see No. 480)

77-606

Derivation of Equations of Motion for Multi-Blade Rotors Employing Coupled Modes and Including High Twist Capability

R. Sopher
Sikorsky Aircraft, Stratford, CT, Rept. No. NASA-CR-137898; SER-50912, 295 pp (Feb 27, 1975)
N76-29152

Key Words: Rotors, Equations of motion, Coupled response

The derivation is described of the equations of motion for a multiblade rotor. The analysis advances on current capabilities for calculating rotor responses by introducing a high twist capability and coupled flatwise-edgewise assumed normal modes instead of uncoupled flatwise and edgewise assumed normal modes. The torsion mode is uncoupled as before. Features inherited from previous work include the support system models, consisting of complete helicopters in free flight, or grounded flexible supports, arbitrary rotor-induced inflow, and arbitrary vertical gust model.

77-607

Model Design and Dynamic Analysis of Rotors

A. Muszynska
Polish Academy of Sciences, Warsaw, Poland, 263 pp (Sept 11, 1975)
(In Polish)
N76-27239

Key Words: Rotors, Dynamic response, Mathematical models

In the very general mathematical model presented, geometric and kinematic as well as physical peculiarities of rotors are expressed. The model is presented in matrix form. Methods of realizing the synthesis of a rotor and its optimization considering selected criteria and limited data are also described. The presented mathematical model of a rotor is very universal and represents the common denominator for the majority of models described and analyzed in the literature. The motion of symmetric models with nonlinear characteristics and the conditions for displacing the situation of relative balance are also analyzed.

77-608

Vibration Energy Method for Rotor Dynamic Optimization

H.R. Simmons

Southwest Research Institute, San Antonio, TX, Hydrocarbon Processing, 55 (11), pp 261-263 (Nov 1976) 5 figs, 11 refs

Key Words: Rotors, Vibration energy methods, Optimization

The vibration energy method may be used to optimize the stiffness and mass distribution for problems of torsional critical speed, unbalance sensitivity and non-synchronous instabilities. Rotor optimization is accomplished by relating the potential critical speed benefit of a proposed fix with its real cost and degree of difficulty. The computer technique for generating the baseline critical speeds and energy distribution tables has been adapted to a portable telephone computer terminal. Thus, this technique is suitable for troubleshooting and correcting field vibration problems.

SHIP

(Also see No. 619)

77-609

Estimation of Ship Shock Parameters for Consistent Design and Test Specification

G.C. Hart, T.K. Hasselman, and W.N. Jones

J.H. Wiggins Co., Redondo Beach, CA 90277, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 155-167 (1976) 13 figs, 6 refs

Key Words: Ships, Shock response spectra

This paper presents the application of a procedure which analytically represents the shock as a time-modulated non-stationary stochastic process with a time varying mean. The parameters which must be quantified for such a representation are the shock's mean value function, time-modulating function, and power spectral density function. These parameters are defined in the paper. Utilizing actual measured ship shock data the parameters are estimated by statistical methods of analysis. Results from different digital data processing techniques are presented to show their influence on the final parameter estimates. The results from this part of the analysis enable digitally simulated test functions to be generated for use in stock tests.

SPACECRAFT

(Also see Nos. 481, 482, 508)

77-610

Exact Modal Analysis for Spinning Flexible Spacecraft

D.H.L. Poelaert

European Space Res. and Tech. Center, Noordwijk, Netherlands, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 8 pp (N76-28297)
N76-28301

Key Words: Spacecraft, Modal analysis

It is shown that with existing theories, it is possible to solve the eigenvalue problem associated with spinning flexible structure, without any a priori spatial discretization of the flexible parts and without introducing any truncated series of assumed modes to expand the deformation field of the actual system.

77-611

Vibration Analysis of the BSE Spacecraft Using Modal Synthesis and the Dynamic Transformation

E.J. Kuhar, Jr.

General Electric Co., Valley Forge, PA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 231-238 (1976) 5 figs, 3 refs

Key Words: Satellites, Spacecraft, Modal synthesis

This paper presents a unique approach taken for the vibration analysis of the Japanese Broadcast Satellite Experiment (BSE). The total spacecraft structure was defined from substructure analyses using a stiffness coupling modal synthesis approach.

77-612

Free Vibration Analysis of Spinning Flexible Space Structures

K.K. Gupta

Jet Propulsion Lab., California Inst. of Tech., Pasadena, CA, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 4 pp (N76-28297)
N76-28298

Key Words: Spacecraft, Natural frequencies, Mode shapes

Efficient computation of natural frequencies and associated free vibration modes of spinning flexible structures was required to accurately determine the nature of interaction between the flexible structure and the attitude control system, which is vital in relating control torques to attitude angles. While structural discretization is effected by the finite element method, the resulting eigenvalue problem is solved by a combined Sturm sequence and inverse iteration procedure that yields a few specified roots and associated vectors.

77-613

Parametric Studies Associated with Spin-Stabilised Flexible Spacecraft

R.H. Dennett
Electronics and Space Systems Group, British Aircraft Corp. (Operating) Ltd., Bristol, England, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 13 pp (N76-28297)
N76-28313

Key Words: Spacecraft, Stability, Modal damping

The trend towards incorporating several sets of deployable booms on spinning passively controlled spacecraft (for example, GEOS) can result in significant configuration (inertia) asymmetry and marginal operational system stability, with the attendant problems in control. The effects of various flexible elements on the conditions for stability of the equilibrium configuration are examined. Modal response and damping are analyzed for a configuration which can be modeled by a (modified) centerbody plus a symmetric pair of long flexible radial booms, represented as pendula. Response is shown to be significantly influenced by thruster position and maneuver strategy. The modal damping provided by an on-board nutation damper, augmented by the natural damping of the booms, is examined against possible system requirements. A discussion is included on the effects of boom stiffness, and the long-term non-linear effects on system spinrate of attitude maneuvers.

77-614

Ground-Test Derived and Flight Values of Damping for a Flexible Spacecraft

F.R. Vigneron
Communications Research Centre, Ottawa, Ontario, Canada, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 9 pp (N76-28297)
N76-28327

Key Words: Spacecraft, Satellites, Modal damping

A method and approximate formula are outlined by which structural modal data, and in particular damping information, might be extrapolated from the one-g ground test state to the zero-g on-orbit state. Natural frequencies for the Communications Technology Satellite (CTS), as calculated using a model confirmed via ground test data, are in reasonable agreement with flight measured values.

77-615

Synthesis of Flexible Spacecraft Command Systems

J.F. LeMaitre, J.P. Chretien, J.P. Jung, P. Rodrigo, and C. Reboulet
Dept. d'Etudes et de Recherches en Technologie Spatiale, Toulouse, France, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 10 pp (N76-28297)
(In French)
N76-28326

Key Words: Spacecraft, Stability analysis, Modal damping, Attitude control systems

The attitude control of spacecraft with weakly damped modes was studied. A canonical form of the transfer function is found which controls launchers under the effect of propellant sloshing. General results are given for both continuous and digital control. Two types of controllers are considered, neglecting or not the knowledge of the natural frequencies of the system. The stability, the trade-off between good attitude control and good damping of the modes and the influence of the sampling period are investigated.

77-616

Design of a Control Loop with Flexibility and In-Flight Identification of the Flexible Modes

A. Beysens
Engins Matra, Velizy, France, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 11 pp (N76-28297)
N76-28322

Key Words: Spacecraft, Attitude control systems, Solar arrays, Modal damping

The principles which have led to the present design of attitude control loops of the geostationary OTS during station keeping maneuvers are introduced, taking into account the flexibility of the solar arrays. The configuration of the loop is detailed: sensor, corrective network, threshold, modulator and thrusters, and the setting are discussed to provide efficient damping of the flexible modes. Then, a method for the in-flight identification of the free-free frequency is presented, based on Fourier analysis of the telemetry signal, in spite of a low TM frequency.

77-617

Interaction Problems Between the Dynamics and Control System for Nonrigid Spacecraft

P.W. Likins

California Univ., Los Angeles, CA, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 7 pp (N76-28297)

N76-28321

Key Words: Spacecraft, Attitude control systems

Specific case studies are employed to illustrate the importance of dynamic modeling and dynamic analysis in the development of attitude control systems for modern spacecraft. Examples include spacecraft that exhibited flight anomalies traced to nonrigidity, and other spacecraft for which nonrigidity has presented problems that were recognized before launch.

77-618

Experimental Liquid/Positive Expulsion Bladder Dynamics

M. Wohltmann

Martin Marietta Aerospace, Orlando, FL 32805, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 285-295 (1976) 25 figs, 5 refs

Key Words: Stability, Sloshing, Missiles

An experimental program was conducted at Martin Marietta Aerospace, Orlando, Florida to investigate fuel slosh effects on the stability and control of the Advanced Strategic Air Launched Missile (ASALM), and to evaluate the performance of two candidate positive fuel expulsion bladder devices. Tank roll tests were performed to determine if twisting of the bladders inside the tank occurred. Liquid expulsion during maximum sloshing was evaluated. Finally, slosh parameters for a bladderless tank were obtained.

77-619

Development of Ship Shock Loads Test for the RGM-84A Missile (Harpoon)

T.L. Eby

Pacific Missile Test Center, Point Mugu, CA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 93-105 (1976) 19 figs

Key Words: Missiles, Ships, Shock tests, Test equipment

The environmental design criteria for the HARPOON missile specified ship shock loads for the three principal missile axes. This paper discusses the development of the device used to verify missile design load requirements. The design verification test was developed and performed using a large shock facility at the Pacific Missile Test Center.

77-620

Determination of Dynamic Loads from Missile Model Wind Tunnel Data

P.G. Bolds and D.K. Barrett

Air Force Flight Dynamics Lab., Wright-Patterson AFB, OH, U.S. Naval Res. Lab., Shock Vib. Bull. No. 46, Pt. 2, pp 197-207 (1976) 30 figs, 3 refs

Key Words: Missiles, Wind tunnel tests

The Air Force Flight Dynamics Laboratory has measured, recorded, and reduced acoustic and vibration data to describe the dynamic pressure environment on the leeward surface of a missile model. The data recorded at specified pitch angles have been selected to illustrate their vortex shedding pattern and their effect upon the natural and dynamic response frequencies of the model to a prototype missile.

77-621

Evaluation of the Harpoon Missile Aircraft Launch Ejection Shock Environment

J.A. Zara, J.L. Gubser, A.G. Piersol, and W.N. Jones

McDonnell Douglas Astronautics Corp., St. Louis, MO, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 107-127 (1976) 19 figs

Key Words: Launching, Shock excitation, Shock response spectra, Missiles

A series of ground launch ejections of a Harpoon missile were performed to establish and evaluate the Harpoon ejection shock environment. The acceleration response of the missile was measured at 30 locations during various simulated ejections from an MAU-9A and an Aero-7A rack. The data were reduced to acceleration shock spectra covering a frequency range from 100 to 10,000 Hz. The results of the study produced considerable information concerning launch ejection shock environments of general interest.

77-622
Modern Spacecraft Dynamics Investigation
P. Boland
Louvain Univ., Belgium, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 9 pp (N76-28297)
N76-28309

Key Words: Spacecraft, Mathematical models, Stability

The modeling of spacecraft as systems of interconnected deformable bodies providing a general approach to the problem of space vehicle dynamics simulation is considered. Derivation procedures for vectorial and matrix equations are examined. Flexibility is accommodated by the adoption of modal coordinates. Results have been compared and provided a valuable cross-check of the methods.

77-623
Dynamics of Tethered Satellites
P. Kulla
European Space Research and Technology Center, Noordwijk, Netherlands, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 5 pp (N76-28297)
N76-28330

Key Words: Satellites, Spacecraft, Dynamic response

It has been proposed to connect satellites to the orbiting Spacelab by tethers. The dynamics of this system are modeled and solutions obtained. The results confirm that the concept is in principle feasible. There are, however, some clear performance restrictions from the system dynamics.

77-624
Analysis of Generalized Forces in the Singular Perturbation Equations of Motion of Flexible Satellites
T.C. Huang and A. Das
Dept. of Engrg. Mech., Wisconsin Univ., Madison, WI, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 9 pp (N76-28297)
N76-28300

Key Words: Satellites, Spacecraft, Perturbation theory

The formulation and existence of a generalized force in the singularly perturbed formulation of flexible satellites is described. The concept of this force sharply reduces the number of degrees of freedom and the equations of motion of satellites with a large number of flexible elements. A stability criterion is proposed for this generalized force.

77-625
Dynamic Stability of Satellites with Liquid Propellants: Results for Symphonie and Application to Other Satellites
R. Metzger
Space Div., Messerschmitt-Boelkow-Blohm G.m.b.H., Ottobrunn, West Germany, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 7 pp (N76-28297)
N76-28329

Key Words: Satellites, Spacecraft, Liquid propellants, Stability

A number of theoretical investigations were carried out to demonstrate the attitude stability of Symphonie in the geostationary transfer orbit. Stability limits and nutation time damping constants were obtained. The theoretical results were confirmed by the performance of both flight models. The results can be applied to other satellite configurations with liquid propellants.

77-626
Effects of Flexibility in an Asymmetric Dual-Spin Spacecraft
F.N. Agrawal
Aerosat SPO Div., European Space Research and Technology Center, Noordwijk, Netherlands, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 8 pp (N76-28297)
N76-28307

Key Words: Spacecraft, Stability

The effects of the flexibility in the momentum wheel of an asymmetric dual-spin spacecraft on its attitude stability are discussed. The instability criteria are given explicitly. It is found that several instability regions can exist. However, for a typical spacecraft the important instability regions occur when the rotor speed is in the neighborhood of either the second natural frequency of the spacecraft or half of the sum of the first and second natural frequencies. As an example, natural frequencies and critical speeds are obtained for a typical spacecraft.

77-627
Nonlinear Dynamics of Flexible Bodies
B. FraeijsdeVeubeke
Lab. de Techniques Aeronautiques et Spatiales, Liege Univ., Belguim, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 9 pp (N76-28297)
N76-28299

Key Words: Spacecraft, Dynamic response

The mean motion of a flexible body is usually taken to satisfy the Tisserand conditions of zero relative momentum and angular momentum associated to a minimum of the relative kinetic energy. The zero momentum condition is preserved but the angular momentum condition is linearized in such a way that the relative displacements are representable exactly by an expansion in natural elastic vibration modes. Hamilton's principle is used to derive all equations of motion, including the mean one, by using the concept of quasi-coordinates. Gravitational potential and thrust vectors, as locally oriented by the body motion and deformation, are accounted. Distortions may be large provided strains remain small.

77-628

Dynamics Modelling and Formulation Techniques for Non-Rigid Spacecraft

C.J.H. Williams

British Aircraft Corp. (Operating) Ltd., Bristol, England, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 18 pp (N76-28297)

N76-28303

Key Words: Spacecraft, Mathematical models

Current techniques for modelling the spacecraft structure and formulating the equations of motion are surveyed. Topics discussed include distributed parameter, discrete parameter, N-body and finite element modelling; floating and fixed spacecraft reference frames; use of quaternion parameters for attitude co-ordinates; quasi co-ordinate forms of Lagrange's equations; and modal analysis using global modes, cantilever modes and assumed models. A number of examples are presented.

77-629

Finite Element Dynamic Analysis of Large Dimensional Flexible Solar Arrays: Necessity of Modal Truncation for the Simulation of Spacecraft Control Manoeuvres

G. LeGuilly and J.G. Ferrante

Societe Nationale Industrielle Aerospatiale, Cannes, France, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 12 pp (N76-28297)

N76-28306

Key Words: Spacecraft, Solar arrays, Mathematical models, Computer programs

As the power requirements for future generation of communication satellites continue to increase, new designs of large solar arrays must be investigated. For this purpose flexible roll-out/fold-out structures represent a very interesting solution. The finite element idealization of such structures and the calculation of fixed base eigen modes by means of a special purpose computer program called DAFSA (Dynamic Analysis of Solar Arrays) are dealt with. Special emphasis is put on local and global modes, and also on the representativity of flexible effect when modal truncation is unavoidable.

77-630

Experimental Determination of Rocket Motor Structural Response to Internal Acoustic Excitation

F.R. Jensen and L.R. West

Hercules, Inc., Bacchus Works, Magna, UT, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 229-243 (1976) 25 figs

Key Words: Solid propellant rockets, Acoustic response, Combustion excitation, Testing techniques

One experimental task was included in this Component Vibration Program to provide data for evaluation of the analytical techniques. The objective of the task was to measure the response of a motor to an acoustic loading that would simulate an unstable acoustic pressure oscillation. This paper describes the testing setup and the testing procedures used to obtain that motor structural response. The test results are also presented and discussed.

77-631

Development of Component Random Vibration Requirements Considering Response Spectra

C.V. Stahle, H.R. Gongloff, and W.B. Keegan

General Electric - Space Div., Valley Forge, PA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 57-76 (1976) 10 figs, 12 refs

Key Words: Spacecraft components, Vibration response spectra, Statistical analysis

A method of determining component random vibration requirements from measured spacecraft test data is presented which enables the final specifications to be placed on a statistical basis. Four methods of sampling PSD spectra are evaluated by comparing the Random Response Spectrum of the resulting PSD with the RRS of the ensemble at several probability values. Measured spectra during spacecraft testing are analyzed using sixth-octave frequencies to define frequency bands or sampling frequencies.

77-632

Dynamics of the Softmounted Spacelab Instrument Pointing System

F. Urban, K. Ernsberger, and H. Heusmann

Dornier-System G.m.b.H., Friedrichshafen, W. Germany, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 10 pp (N76-28297)

N76-28305

Key Words: Spacecraft equipment response, Mountings, Digital simulation

The description and analysis of a new kind of a 3-axis controlled gimbal system for very precise pointing and stabilization of Spacelab experiments are presented. A special feature of this design is the flexible suspension (softmount) which reduces the sensitivity of this gimbal configuration to disturbances caused by crew motion and Shuttle Orbiter jet firing.

77-633

Systems Equations and Control of an Orbiting Flexible Telescope

H. Bremer

Inst. B fuer Mechanik, Technische Universitaet, Munich, W. Germany, In: ESA Dyn. and Control of Non-rigid Space Vehicles 1976, 10 pp (N76-28297)

N76-28304

Key Words: Spacecraft equipment response

Hybrid non-rigid spacecrafts such as an elastic telescope with internal rigid bodies cannot easily be treated by direct transfer of the methods of elastodynamics. By a generalization of Rayleigh's quotient, however, a useful approximation can be made in order to obtain the equations of motion including the coupling moment between elastic vibrations and rigid body motion.

77-634

Feasibility Study of an Acoustic Enclosure for Shuttle Payloads

M. Ferrante, C.V. Stahle, and F.J. On

General Electric Space Div., Philadelphia, PA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 2, pp 209-226 (1976) 15 figs, 13 refs

Key Words: Spacecraft equipment, Acoustic insulation

This paper presents the analysis, design and experimental evaluation of a viscoelastic laminated acoustic enclosure that will shield sensitive instruments from the high low-frequency acoustic environment of the Space Shuttle payload bay.

77-635

Statistical Determination of Random Vibration Requirements for Subassembly Tests

J.M. Medaglia

General Electric Space Div., Philadelphia, PA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 4, pp 77-91 (1976) 12 figs, 5 refs

Key Words: Spacecraft equipment response, Satellites, Random vibration, Testing techniques, Statistical analysis

A statistical method for determining subassembly random vibration requirements which is compatible with the requirements applied to individual electronic component packages has been developed. Quantitative estimates of the damage potential of the subassembly random vibration environment and of the component specification are compared at various probability levels to arrive at a subassembly input requirement.

77-636

An Experimental Investigation of the Axial Forces Generated by the Oblique Water Entry of Cones

J.L. Baldwin

Naval Surface Weapons Ctr., White Oak, Silver Spring, MD, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 163-172 (1976) 11 figs, 4 refs

Key Words: Reentry vehicles, Conical shells, Impact shock, Landing, Water

An experimental program is described in which the axial acceleration was measured during the oblique water entry of cone-nosed missiles.

77-637

Simulation of X-Ray Blowoff Impulse Loading on a Reentry Vehicle Aft End Using Light-Initiated High Explosive

R.A. Benham

Sandia Laboratories, Albuquerque, NM 87115, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 183-189 (1976) 10 figs, 9 refs

Sponsored by ERDA

Key Words: Reentry vehicles, Nuclear explosion effects

This paper describes an experimental method in which X-ray blowoff impulse effects are simulated by the detonation of a spray deposited coating of explosive initiated by an intense flash of light. A specific experiment is described in which the complex aft surface of an advanced development reentry vehicle is simultaneously loaded with a distributed impulse including load step discontinuities.

77-638

Longitudinal Vibration Characteristics of the Space Shuttle Solid Rocket Booster Test Segment

J.C. Bartlett and D.L. Linton

IBM Federal Systems Div., Huntsville, AL 35805, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 93-105 (1976) 18 figs, 5 refs

Key Words: Booster rockets, Finite element technique, NASTRAN (Computer program), Longitudinal response

This paper deals with the axisymmetric longitudinal vibration modes of the Space Shuttle Solid Rocket Booster (SRB) Test Segment. An explanation of the methods used to conduct this dynamic analysis is given and the finite element models used with the NASTRAN Computer Program are defined. A short test segment of the SRB was analyzed with and without a test fixture to evaluate the longitudinal dynamic characteristics of the test segment and to demonstrate the feasibility of determining these modes by testing with a 100,000 force-pound (444,822 newton) vibration exciter.

77-639

Vibration Characteristics of 1/8-Scale Dynamic Models of the Space Shuttle Solid Rocket Boosters

S.A. Leadbetter, W.B. Stephens, J.L. Sewall, J.W. Majka, and J.R. Barrett

NASA, Langley Research Ctr., Hampton, VA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 67-91 (1976) 23 figs, 22 refs

Key Words: Booster rockets, Vibration tests, Natural frequencies, Mode shapes, Cylindrical shells

Results of vibration tests and analyses of six 1/8-scale models of the space shuttle solid rocket booster tanks are reported. Natural vibration frequencies and mode shapes were obtained for these aluminum shell models having internal solid fuel configurations corresponding to launch, midburn (maximum dynamic pressure), and near end-burn (burn-out) flight conditions. Test results for longitudinal, torsional, bending, and shell vibration frequencies are compared with analytical predictions derived from thin shell models, and finite-element plate and beam models.

77-640

A Study of the Space Shuttle Solid Rocket Booster Nozzle Water Impact Recovery Loads

E.A. Rawls and D.A. Kross

Chrysler Corp., Space Div., New Orleans, LA, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 3, pp 149-162 (1976) 16 figs, 7 refs

Key Words: Booster rockets, Impact shock, Landing, Water

Solid Rocket Booster (SRB) nozzle water impact environments are predicted by simplified analytical techniques in combination with scale model testing. The analytical approach, which provides preliminary design data, is based on an equivalent wedge approximation for the significant design events of maximum positive and negative applied loadings. The experimental program is performed to verify the analysis and to obtain more detailed design data.

STRUCTURAL

(Also see Nos. 471, 485)

77-641

Dynamic Behaviour of Complex Structures, Using Part Experiment, Part Theory

J.C. Cromer and M. Lalanne

Institut National des Sciences Appliquees, Villeurbanne, France, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 177-185 (1976) 6 figs, 9 refs

Key Words: Complex structures, Substructure technique

The dynamic behaviour of a complex system is obtained using a substructure technique. In order to reduce the large number of degrees of freedom of practical structures, the normal modes of some substructrures are used as generalized coordinate. Substructures whose properties are determined by experiments are connected to those modeled by finite element techniques. Tests are conducted on simple beams in bending in order to determine the influence of the number of modes and of the experimental data. The method is then applied to a complex practical structure and agreement between experimental and theoretical results is shown to be good.

77-642

Axisymmetric Structural Loading for a Traveling Overpressure Pulse

J.J. Farrell, D.J. Ness, and G.M. Teraoka
TRW Defense and Space Systems Group, Redondo Beach, CA 90278, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 147-151 (1976) 5 figs, 2 refs

Key Words: Nuclear explosion damage, Protective shelters, Finite element techniques, Mathematical modeling

Survivability evaluation of protective structures under nuclear attack environments is often aided by finite element analyses. Such analyses have considered two-dimensional axisymmetric models. This paper examines several implications of using a zeroth order Fourier expansion of the nuclear loading on an axisymmetric finite element structural model. Sample problem results are presented and discussed. General considerations of this locally axisymmetric representation of the nuclear blast loading are also discussed.

77-643

Statistical Model of Sonic Boom Structural Damage

R.L. Hershey and T.H. Higgins
Booz-Allen Applied Research, Inc., Bethesda, MD, Rept. No. FAA-RD-76-87, 142 pp (July 1976) AD-A028 512/2GA

Key Words: Sonic boom, Structural response, Statistical analysis

The probabilities of structural damage from sonic booms were estimated for various susceptible structural elements using a statistical modeling technique.

77-644

Biaxial Effects in Modelling Earthquake Response of R/C Structures

H. Takizawa and H. Aoyama
Dept. of Engrg., Hokkaido Univ., Sapporo, Hokkaido, Japan, Intl. J. Earthquake Engr. Struc. Dynam., 4, pp 523-552 (1976)

Key Words: Structural response, Seismic excitation, Earthquakes

Recent studies reveal that R/C structural members subjected to biaxial flexure due to two-dimensional earthquake excitation can deform much more than would be predicted by conventional one-dimensional response analysis. The biaxial flexure may therefore have a significant effect on the dynamic collapse process of structures subjected to intense ground motions. The present paper is intended to develop a new formulation of the two-dimensional restoring force model of R/C columns acted upon by biaxial bending moments, and to discuss the dynamic response properties of R/C structures.

77-645

The Dynamic Foundation Interaction of Multistorey Frames

A.A. Dumanoglu and R.T. Severn
Karadeniz Technical Univ., Turkey, Intl. J. Earthquake Engr. Struc. Dynam., 4, pp 589-608 (1976)

Key Words: Structural response, Seismic excitation, Computer programs

This paper discusses the extent to which foundation properties influence the response of some framed structures to earthquakes. Three stages can be isolated, the first of which checks the validity of a theoretical method by means of model studies. The second stage uses a proven computer program for a parametric study to obtain a large number of results, which give a good indication of the effect of different foundation conditions on this type of structure. Some calculations are also made in which the foundation is represented by equivalent springs instead of finite elements. In the third stage dynamic response was considered. A shaking table was built on which the models were subjected to a number of actual earthquake records, which had been suitably scaled and recorded on magnetic tape.

77-646

Dynamic Earthquake Analysis of a Bottom Supported Industrial Boiler

N.J. Monroe and N. Dasa
The Babcock & Wilcox Co., North Canton, OH 44720, U.S. Naval Res. Lab., Shock Vib. Bull., No. 46, Pt. 5, pp 1-16 (1976) 5 figs,

Key Words: Boilers, Seismic design, Mathematical models

In this paper a dynamic earthquake analysis of a large bottom supported boiler is presented. The assumptions and modeling techniques necessary to developing the mathematical model are stated and the dynamic response of the structure and the resultant stresses are tabulated. The results of the dynamic analysis are compared to the results of the static earthquake analysis which is presently required by the various nationally accepted building codes. Results are presented of a dynamic analysis of the same boiler using a more detailed mathematical model. The advantages of both models are discussed and recommendations are made based on a completion of the results presented.

TURBOMACHINERY

(See No. 527)

USEFUL APPLICATION

77-647

A Preliminary Analysis of Ski Release Binding Dynamic Properties

C.D. Mote, Jr. and M.L. Hull
Dept. of Mech. Engrg., Univ. of California, Berkeley, CA, J. Dyn. Syst., Meas. and Control, Trans. ASME, 98 (3), pp 301-308 (Sept 1976) 6 figs, 21 refs. Paper No. 76-Aut-BB

Key Words: Skis, Mathematical models

A piecewise, linear, two degree of freedom, ski release binding dynamic system model is presented for an elementary analysis of binding performance. Dynamic performance criteria and techniques for quantitative evaluation of ski release binding properties are discussed.

AUTHOR INDEX

CALENDAR

MEETING	DATE	LOCATION	CONTACT
	1977 APR		
Lubrication Symposium	11-13	St. Louis, MO	ASME Hq.
American Power Conference, Ill. Inst. Tech.	18-20	Chicago, IL	R.A. Budenholzer, Dir. APC c/o IIT, 10 W. 35th St. Chicago, IL 60616
Design Engineering Conference and Show, ASME	18-20	New York, NY	ASME Hq.
2nd International Conference on Vehicle Structural Mechanics	18-20	Southfield, MI	SAE Hq.
Mini-Conference on Transportation	19-21	Ann Arbor, MI	Highway Safety Research Institute The University of Michigan Ann Arbor, MI 48109 Tele. (313) 764-2168
Diesel and Gas Engine Power Conference and Exhibit, ASME	24-28	Dallas, TX	ASME Hq.
IES Annual Meeting	24-27	Los Angeles, CA	IES Hq.
Meeting on Wear of Materials	25-27	St. Louis MO	Prof. K. C. Ludema, Dept. of ME, The University of Michigan Ann Arbor, MI 48109
9th Space Simulation Conference IES-AIAA-ASTM NASA	26-28	Los Angeles, CA	IES Hq.
International Conference - Tribology	April	Cambridge, MA	Lt. R.S. Miller, Code 211 Office of Naval Research, Ballston Tower No. 1, Arlington, VA 22117 Tele. 692-4421
	MAY		
23rd International Instrumentation Symposium	1-5	Las Vegas, NV	ISA Hq.
Symp. on Fatigue Testing of Weldments	1-6	Toronto, Canada	ASTM Hq., Ms. J.B. Wheeler
Offshore Technology Conference	2-5	Houston, TX	Society of Petroleum Engineers 6200 N. Central Expressway Dallas, TX 75206
Symp. on Statistical Design of Fatigue Experiments	5	Toronto, Canada	ASTM, Ms. J.B. Wheeler
American Helicopter Society Annual National Forum	9-11	Washington, D.C.	American Helicopter Society Lounsbury, Exec. Dir., 30 East 42nd St. New York, NY 10017
National Plant Engineering and Maintenance Show and Conference	9-12	Chicago IL	Clapp & Poliak Banner & Greif Ltd. 369 Lexington Ave. New York, NY 10017

CALENDAR

MEETING	DATE	LOCATION	CONTACT
	1977 MAY		
31st Annual Technical Conference, ASQC	16-18	Philadelphia, PA	R.W. Shearman, ASQC Hq.
Society for Experimental Stress Analysis 1977 Spring Meeting & Exposition	15-20	Dallas, TX	SESA Hq., B. E. Rossi
National Aerospace Electronics Conference	17-19	Dayton, OH	NAECON 140 E. Monument Ave. Dayton, OH 45402
Society of Naval Architects and Marine Engineers 1977 Spring Meeting and STAR Symposium	25-27	San Francisco, CA	A. J. Haskell, Matson Navigation Co. 100 Mission St. San Francisco, CA 94105
6th Canadian Congress of Applied Mechanics	30 May - 3 Jun	Vancouver, Canada	Prof. J.P. Duncan, ME Dept. Univ. of British Columbia Vancouver, BC, Canada
Symposium on Tire Vibration and Noise	May		H. G. Schwartz ASTM Subcommittee F-9.93 on Papers & Symposium E. I. duPont 40 Buchtel Ave. Akron, OH 44308
	JUNE		
Fuels and Lubricants Meeting, SAE	7-9	Tulsa, OK	SAE Hq.
Acoustical Society of America, Spring Meeting	7-10	State College, PA	J. C. Johnson, Appl. Res. Lab. Pennsylvania State University Box 30 State College, PA 16801
National Computer Conference	13-16	Dallas, TX	Ms. P. Isaacson University of Texas Box 688 Richardson, TX 75080
Applied Mechanics Conference, ASME	14-16	New Haven, CT	ASME Hq.
Fluids Engineering Conference	15-17	New Haven, CT	ASME Hq.
4th International Conference on Fracture	19 24	Waterloo, Canada	Prof. T. Kawasaki, Sec. Gen. Int'l. Congress of Fracture c/o Dept. of ME Tohoku University Sendai, Japan
Design Automation Conference	20-22	New Orleans, LA	H. Hayman Box 639 Silver Spring, MD 20901
Symposium on Dynamic Tests on Soil & Rock, ASTM	26 Jun - 1 Jul	Denver, CO	ASTM Hq., Ms. J.B. Wheeler

CALENDAR

MEETING	DATE	LOCATION	CONTACT
	1977 AUG		
Society of Automotive Engineers 1977 West Coast Meeting	8-11	Vancouver Canada	SAE Hq., A.L. Weldy
	SEPT		
Vibrations Conference, ASME	26-28	Chicago, IL	ASME Hq.
	OCT		
48th Shock and Vibration Symposium	18-20	Huntsville, AL	Henry C. Pusey, Director The Shock and Vibration Information Center, Code 8404 Naval Research Laboratory Washington, D.C. 20375 Tele. (202) 767-3306
	NOV		
Winter Annual Meeting, ASME	27 Nov - 2 Dec	Atlanta, GA	ASME Hq.

CALENDAR ACRONYM DEFINITIONS AND ADDRESSES OF SOCIETY HEADQUARTERS

AFIPS:	American Federation of Information Processing Societies 210 Summit Ave., Montvale, N.J. 07645
AGMA:	American Gear Manufacturers Association 1330 Mass. Ave., N.W. Washington, D.C.
AIAA:	American Institute of Aeronautics and Astronautics, 1290 Sixth Ave. New York, N.Y. 10019
AIChE:	American Institute of Chemical Engineers 345 E. 47th St. New York, N.Y. 10017
AREA:	American Railway Engineering Association 59 E. Van Buren St. Chicago, Ill. 60605
AHS:	American Helicopter Society 30 E. 42nd St. New York, N.Y. 10017
ARPA:	Advanced Research Projects Agency
ASA:	Acoustical Society of America 335 E. 45th St. New York, N.Y. 10017
ASCE:	American Society of Civil Engineers 345 E. 45th St. New York, N.Y. 10017
ASME:	American Society of Mechanical Engineers 345 E. 47th St. New York, N.Y. 10017
ASNT:	American Society for Nondestructive Testing 914 Chicago Ave. Evanston, Ill. 60202
ASQC:	American Society for Quality Control 161 W. Wisconsin Ave. Milwaukee, Wis. 53203
ASTM:	American Society for Testing and Materials 1916 Race St. Philadelphia, Pa. 19103
CCCCAM:	Chairman, c/o Dept. ME, Univ. Toronto, Toronto 5, Ontario, Canada
IEEE:	Institute of Electrical and Electronics Engineers 345 E. 47th St. New York, N.Y. 10017
IES:	Institute Environmental Sciences 940 E. Northwest Highway Mt. Prospect, Ill. 60056
IFToMM:	International Federation for Theory of Machines and Mechanisms, US Council for TMM, c/o Univ. Mass., Dept. ME, Amherst, Mass. 01002
INCE:	Institute of Noise Control Engineering P.O. Box 3206, Arlington Branch, Poughkeepsie, N.Y. 12603
ISA:	Instrument Society of America 400 Stanwix St., Pittsburgh, Pa. 15222
ONR:	Office of Naval Research Code 40084, Dept. Navy, Arlington, Va. 22217
SAE:	Society of Automotive Engineers 400 Commonwealth Drive Warrendale, Pa. 15096
SEE:	Society of Environmental Engineers 6 Conduit St. London W1R 9TG, England
SESA:	Society for Experimental Stress Analysis 21 Bridge Sq. Westport, Conn. 06880
SNAME:	Society of Naval Architects and Marine Engineers, 74 Trinity Pl. New York, N.Y. 10006
SVIC:	Shock and Vibration Information Center Naval Research Lab., Code 8404 Washington, D.C. 20375
URSI-USNC:	International Union of Radio Science - US National Committee c/o MIT Lincoln Lab., Lexington, Mass. 02173

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Volume 9 No. 3 March 1977

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